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Additional inventors are being named on the _____ separately numbered sheets attached hereto

TITLE OF THE INVENTION (280 characters max)

A CHEMICAL SENSOR AND METHOD OF USING OPTICALLY ANISOTROPIC MATERIAL

Direct all correspondence to:

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ENCLOSED APPLICATION PARTS (check all that apply)

<input checked="" type="checkbox"/> Specification	Number of Pages	18	<input type="checkbox"/> CD(s), Number	<input type="text"/>
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Respectfully submitted,

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TITLE OF THE INVENTION

A chemical sensor and method of using optically anisotropic material

FIELD OF THE INVENTION

[0001] The present invention relates to chemical sensors. More specifically, the present invention is concerned with a chemical sensor and method of using changes occurring in the optical anisotropy of the sensor.

BACKGROUND OF THE INVENTION

[0002] Chemical detection is often mandatory for industrial or safety applications and simple reliable sensors could be implemented for process control or for security monitoring.

[0003] A number of different chemical sensors for detection of chemicals are known in the art, usually based on changes in characteristics such as physical, chemical, electrochemical or optical properties. Electronic methods are sometimes used, using the ability of composite polymers to have electrical impedance varying upon exposure to a vapor for example.

[0004] The U.S. patent 5,512,882 (Stetter, 1996) describes a sensor comprising a polymer having a physical structure that is altered by a vapor to be detected, in such a way that detection is performed through expansion or disintegration, and electrically conductive elements that are interspersed with, or separated by, the polymer. Commercial products of such a sensor are made by the manufacturers Cyrano Sciences Inc. which has developed "electronic noses" consisting of different conducting polymers. Each polymer is sensitive to a different compound. The polymer absorbs vapor and swells when placed in contact with a

specific chemical vapor causing electrical resistance of the polymer to vary with the concentration of the compound. However, this type of sensors generally requires using specific polymers depending on the chemical species to be detected, which makes them complicated to produce and to use.

[0005] Optically based chemical sensors are also known, among which are found fiber optic chemical sensors (FOCS). A number of them uses the changes in guiding properties of an optical fiber, including transmission parameters such as intensity and exit angle. For example, the U.S. patent 4,846,548 (Klainer, 1989) relates to a FOCS measuring changes in the total internal reflection characteristics produced by changes in the index of refraction of a clad or layer of a material that reacts with the chemical or biological species. By a specific selection of the reactive layer or clad, such a chemical sensor can be adaptable to the analysis of several target molecules or classes of compounds. A similar approach is presented in U.S. patent 5,828,798 (Hopenfield, 1998), which makes use of a plastic fiber optic sensor having a clad selected to selectively decompose in the presence of an analyte to be detected (i.e a material for analysis). The fiber has a clad with an index of refraction slightly above the one of the core and it has a loop shape to promote high order propagation modes so that the transmitted light intensity increases in presence of the substance to detect. Therefore, these optical methods require specific cladding materials depending of the chemical species to be detected, which make them not very practical in industrial applications where different chemical species can be present

[0005] Basically, in chemical sensors, the contact with a specific chemical or with a class of chemicals changes the response of the sensors. In order to increase the contact surface with chemicals, porous materials are often used. For such materials, adsorption and capillary condensation of vapors and gases inside their pores are well known phenomena [Steel, W. A. *The interaction of gases with solid surfaces* (Pergamon, Oxford, 1974) & Adamson, A.W. *Physical*

chemistry of surfaces (Wiley, New York, 1982).

[0007] The U.S. patent 5,250,095 (Sigel, 1993) describes a method for making and using a porous glass optical fiber sensor. It is based on the change of the optical transmission of light intensity due to absorption or scattering through a porous optical fiber when exposed to a vapor or a gas that fills the porous structure. A similar method described in the U.S patent 6,375,725 (Bernard, 2002) make uses of an optical fiber with at least one porous portion, which in presence of a gas/vapor sorbent has lower guiding and transmission properties that can trigger an alarm by means of an electronic detection circuit. However, in both cases, the fragility of porous optical fiber does not make these methods attractive for industrial applications where robust sensors are required. Moreover, these types of light intensity-based sensors may suffer from lack of sensitivity in low concentration applications and may require frequent recalibration.

[0008] Other optical chemical sensors use a spectroscopic approach and rely on light absorption at specific wavelengths to detect chemical species. For instance, the U.S. patent 5,308,771 (Zhou, 1994) uses one or more supports, such as beads, which carry a thin film of polymer substrate, which has a porous matrix and an immobilized sensing reagent. The sensing reagent, such as bromophenol red or vanillin, has different absorption spectra in the presence and in the absence of an analyte. An analysis of those differences makes possible the use of this device for detection and quantification purposes, but only for specific analytes.

[0009] Still other optical chemical sensors are based on interferometry. For example, the sensor described in U.S. patent 6,130,748 (Krüger, 2000) uses an interferometric filter made from porous silicon. Detection or determination of a substance concentration in a fluid is based on the change in the optical property of porous silicon as a function of the refractive index of the substance present in the pores of the porous silicon, or of the fluid containing the substance. Another U.S

patent 8,248,539 B1 (Ghadiri, 2001) uses wavelength shifts in the reflectometric interference spectra of a porous semiconductor substrate such as silicon for a highly sensitive detection, identification and quantification of small analyte molecules. Nonetheless, the later method requires having a specific recognition partner, immobilized on the porous silicon substrate, to detect a specific analyte.

[0010] Birefringent porous silicone has been described as a highly sensitive element for vapors and gases [Gross, E. et al. *J. Appl. Phys.* 90 n°7 (2001) pp 3529-3532 "Highly sensitive recognition element based on birefringent porous silicon layers"]. The spectral shift resulting from condensation of vapors or gases inside the pores is directly related to the dielectric constant of the adsorbate and the filling factor of the pores: the higher the larger spectral shift. Although porous silicone has a great potential for sensor applications, this material is very fragile due to its high porosity (usually over 50-80%) and to the fact very thin layers are used (typically 10-100 μm) which make it difficult to use for robust sensor applications. Another drawback is that spectral shifts occur in the far red and near infrared region (~800-1000nm) which means that the human eye could not be used as the light detector. Aging of porous silicon related to surface oxidation is a well known phenomenon [Canham, L.T. in *Properties of Porous Silicon* Canham L. Ed., EMIS Datareviews series n°10, INSPEC publ., pp 154-157], which may also be a severe drawback for development of this type of sensors for long term service.

[0011] Surface color changes in thin (i.e. of a thickness less than 300 nm) porous silicon films caused by vapor exposure close to saturation has been reported [Bjorklund, R. B. et al. *Appl. Phys. Lett.* 69 (20) (1996) pp 3001-3003 "Color changes in thin porous silicon films caused by vapor exposure" & Zangoole, S. et al. *Sensors and Actuators B* 43 (1997) pp 168-174]. Those color changes characterized by ellipsometry were related to the refractive index of the solvents condensing into the pores and replacing air. Since lower partial pressures of solvent caused no color changes in the film, only the variation in the

ellipsometric angles at certain energies could be sufficient for sensing applications.

[0012] The US patent 5,338,415 (Sailor and al, 1994) disclosed a simple chemical sensor based on intensity change of visible photoluminescence of porous silicon when exposed to solvents.

[0013] The U.S. patent 4,732,480 (Fortunato, 1988) describes an interferometric device for the detection and/or analysis of gas using a photoelastic modulator.

[0014] Chemical sensors may be of interest in end-of-service life indicators for air purifying devices. Air purifying devices, among them air purifying respirator cartridges and canisters are widely used in the civil as well in the military industry to protect the workers against harmful effect of toxic materials. Such devices usually consist of a filter chamber filled with an adsorbent material that traps vapors or gases on its surface or into its porous structure. Once the adsorbent material is completely filled, the air-purifying device no longer protects the user against the contaminant. This could have dramatic effects especially when the contaminant has poor warning properties, i.e. if its odor, taste or irritation limit is greater than the permissible exposure limit or if there is insufficient toxicological data to determine an exposure limit.

[0015] In establishing new certification standards in 1984, the U.S. National Institute for Occupational Safety and Health (NIOSH) encouraged the development of active end-of-life indicators. Such indicators should detect the presence contaminant and provide an unambiguous signal warning the user that the filter of the air-purifying device is almost exhausted. In addition to promoting premature disposal of adsorbent filters (still having potential absorbency to toxic gases or vapors), they provide an easy and cheap way to monitor the uses. There are many chemical sensors that are patented for end of service indicators.

[0016] Numerous patents for end of service indicators involve a visual color change that warns the user to replace the filter. Such color changes are induced by chemical reactions of a usually single use color indicator. For instance, the U.S. patents 4,154,586 (Jones, 1979) and 4,530,708 (Jones, 1985) use oxidation of the color indicator enhanced by an upstream catalytic/oxidizing agent that activates the gas or vapor so that it can be more easily detected by the indicator.

[0017] The position of the color indicator within the absorbent material is crucial in order to give a warning before all the absorbent bed is filled with the contaminants. In the U.S. patent 4,684,380 (Leichnitz, 1987), the color granular indicator is placed between two discs that are permeable to the respiration gas and it is located in a container open to the gas flow and extending to a given immersion depth into the filter material. Other designs are possible like the one described in U.S. patent 4,326,514 (Elan, 1982), where the colorimetric indicator is in a sheet form and is positioned along an inner transparent sidewall of a respirator cartridge or canister. Another lateral positioning is described in the PCT patent application WO 02/22237 A1 (Curado, 2002).

[0018] However, a drawback of chemical color indicators is that they are usually very specific to the chemical or class of chemicals (such as acids) they should react with. For instance, the U.S. patent 4,155,358 (McAllister, 1979) describes a disposable valveless chemical cartridge respirator for filtration of a vinyl chloride monomer having an end of service life indicator. Reactivity depends on the chemical nature of the substances to be detected. If different types of chemicals have to be detected, different types of color indicators could be combined as mentioned in the PCT patent application WO 02/22237 A1 (Curado, 2002).

[0019] The U.S. patent 4,146,887 (Magnante, 1979) concerns an

exothermic sensor integrated into an electrical circuit that monitors the heat involved during adsorption of a vapor or a gas into a sensor absorbent.

[0020] The U.S patent 6,375,726 (Bernard, 2002) uses a glass optical waveguide with at least one porous portion, which, in presence of a gas/vapor sorbent, has lower guiding and transmission properties that can trigger an alarm thanks to an electronic detection circuit. The porous optical fiber requires a defined porous cladding which, when they are filled with solvents, affects the guiding properties of the optical fiber by increasing its guiding losses of the fiber. The performance of the described porous optical fiber could be increased with a longer porous section, a thinner porous cladding or a tighter curvature, but since the fiber remains relatively fragile and brittle, difficulties arise when this fiber is included inside the absorbent bed.

[0021] Therefore, there is still a need in the art for a chemical sensor and method, which mitigate the problems of the prior art.

OBJECTS OF THE INVENTION

[0022] An object of the present invention is therefore to provide an improved chemical sensor and a method of using changes occurring in the optical anisotropy of the sensor.

[0023] Other objects, advantages and features of the present invention will become more apparent upon reading of the following non-restrictive description of embodiments thereof, given by way of example only with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] In the appended drawings:

[0025] Figure 1a is a schematic representation of a sensor set-up according to an embodiment of the present invention using transmitted light;

[0026] Figure 1b is a schematic representation of the sensor set-up of Figure 1 used according to an embodiment of the first aspect of the present invention;

[0027] Figure 1c is a schematic representation of the sensor set-up of Figure 1 used according to an embodiment of the second or the third aspect of the present invention;

[0028] Figure 2a is a schematic representation of a sensor set-up using single light reflection and parallel polarizers used according to another embodiment of the first aspect of the present invention;

[0029] Figure 2b is a schematic representation of sensor set-up an using multiple light reflections and parallel polarizers used according to a further embodiment of the first aspect of the present invention;

[0030] Figure 2c is a schematic representation of sensor set-up an using multiple light reflections and crossed polarizers used according to still a further embodiment of the first aspect of the present invention;

[0031] Figure 3a is a schematic representation of a birefringence set-up using transmission in crossed polarizers and reflection in parallel polarizers;

[0032] Figure 3b is the schematic representation of Figure 3a wherein the optical path into the anisotropic material for the parallel ray is twice the one for the perpendicular ray;

[0033] Figure 4a is the theoretical transmittance calculated in a wavelength range comprised between $\lambda = 300$ nm and $\lambda = 1000$ nm for an optical birefringent material of a variable thickness d placed at 45° between ideal crossed polarizers;

[0034] Figure 4b is the theoretical transmittance calculated in a wavelength range comprised between $\lambda = 300$ nm and $\lambda = 1000$ nm for an optical birefringent material with a variable birefringence Δn and a constant thickness d , placed at 45° between ideal crossed polarizers;

[0035] Figure 4c is the theoretical transmittance calculated in a wavelength range comprised between $\lambda = 300$ nm and $\lambda = 1000$ nm for an optical birefringent material of a constant thickness placed at 45° between ideal crossed and parallel polarizers;

[0036] Figure 5a is a schematic representation of an optical birefringence set-up using transmitted light guided by optical fibers;

[0037] Figure 5b is a schematic representation of an optical birefringence set-up using reflected light guided by optical fibers;

[0038] Figure 5c is a schematic representation of an optical birefringence set-up using reflected and transmitted light guided by optical fibers;

[0039] Figure 5d is a schematic representation of an optical

birefringence sensor setup using reflected light in a single optical fiber;

[0040] Figure 8 is a schematic cross-section of an air purifying cartridge with an optical birefringence sensor using transmitted light guided by optical fibers showing the positioning of the sensor inside the cartridge;

[0041] Figure 7 is a schematic representation of an optical birefringence sensor comprising an anisotropic material placed at 45° between two preferably crossed polarizers into a perforated tube inserted inside a filtration cartridge;

[0042] Figure 8 is a schematic cross-section of multiple optical birefringence sensors using reflected light inserted into an air purifying on a transparent wall, according to the first aspect of the present invention;

[0043] Figure 9 is a graph of the transmitted power as a function of the wavelength for an optical birefringence porous glass flat sample placed at 45° between two crossed polarizers under dry nitrogen condition;

[0044] Figure 10 is a graph of the transmitted power as a function of the wavelengths for a birefringence porous glass 600 μm thick flat sample placed at 45° between two crossed polarizers under dry nitrogen condition with no solvent or with acetonitrile or toluene;

[0045] Figure 11 is a graph of the transmitted power at 450 nm and 600 nm as a function of time for a birefringent porous glass 600 μm thick flat sample placed at 45° between two crossed polarizers under dry nitrogen condition with no solvent or with toluene;

[0046] Figure 12 is a graph of the transmitted power at 450 nm and 600 nm as a function of time for a birefringent porous glass 600 μm thick flat sample placed at 45° between two crossed polarizers under dry nitrogen condition with no solvent or with acetonitrile;

[0047] Figure 13a is a graph of the variation of intensity measured at 550 nm and 800 nm of an optical birefringent porous glass sensor in a transmission mode (similar to Figure 5a) inserted in the middle of an activated carbon bed of an organic vapor cartridge challenged at 32 L/min with 1000 ppm of toluene;

[0048] Figure 13b is a graph of the intensity ratios of signals measured at 550 nm and 800 nm in the experiment of Figure 12a; and

[0049] Figure 13c is a graph of spectra measured during the experiment of Figure 13a for various times.

DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0050] Generally stated, the present invention provides a chemical sensor and method for detecting the presence of liquid, gas or vapor of chemical substances through changes in the optical anisotropy of the sensor upon exposure to these liquid, gas or vapor substances.

[0051] More precisely, the present invention is based on changes of optical anisotropy that occurs in certain class of materials, especially but not limited to, porous optical materials such as porous glass and polymeric materials, upon exposure to liquid, gas or vapors of chemical substances.

[0052] Figure 1a is a schematic representation of a sensor set-up using transmitted light, where S is the light source, which may be natural daylight for example, F1 and F2 are optional filters, P1 and P2 are optional polarizers, A is an anisotropic material and D is a light detector, which may be the human eye for example.

[0053] In a first aspect of the present invention, the change in optical anisotropy is observed as optical birefringence, using a set-up illustrated in Figure 1b for example.

[0054] In a second aspect of the present invention, the change in optical anisotropy is observed as dichroism or selective absorption, using a set-up illustrated in Figure 1c for example.

[0055] In a third aspect of the present invention, the change in optical anisotropy is observed as an anisotropic diffusion of light or an anisotropic scattering of light, for which the set-up illustrated in Figure 1c for example may also be used.

[0056] The first aspect of the present invention will now be explained with more details, in relation to the figures of the appended drawings.

[0057] Figure 1b is a schematic representation of a sensor optical birefringence configuration set-up used in the present invention using transmitted light.

[0058] Figure 2a is a schematic representation of a sensor birefringence set-up using single light reflection and parallel polarizers. Figure 2b illustrates an optical birefringence set-up using multiple light reflections and parallel

polarizers. Figure 2c illustrates an optical birefringence set-up using multiple light reflections and crossed polarizers M1 and M2 are mirrors, P is a polarizer and other letters are defined in Figure 1.

[0059] Figure 3a is a schematic representation of a birefringence set-up using transmission in crossed polarizers and reflection in parallel polarizers, where F1, F2 and F3 are optional filters, R is a partially reflecting mirror, D1 and D2 are light detectors and other letters are defined in Figure 1. In this configuration, the optical path into the anisotropic material is the same for the two detected light beams. A same set-up is used in Figure 3b but in a configuration wherein the optical path into the anisotropic material for the parallel ray is twice the one for the perpendicular ray.

[0060] The theoretical transmittance is calculated in a wavelength range comprised between $\lambda = 300$ nm and $\lambda = 1000$ nm for an optical birefringent material ($\Delta n = 0.0015$) of variable thickness $d = 100\mu\text{m}$ (circles), $d = 200\mu\text{m}$ (triangles), $d = 400\mu\text{m}$ (squares) and $d = 600\mu\text{m}$ (diamonds), and for an optical birefringent material with variable birefringence $\Delta n = 0.0005$ (circles), $\Delta n = 0.0010$ (triangles), $\Delta n = 0.0015$ (squares) and $\Delta n = 0.0020$ (diamonds) and a constant thickness $d = 400\mu\text{m}$ (Figure 4b). In both cases, the optical birefringent material is placed at 45° between ideal crossed polarizers. Figure 4c shows the theoretical transmittance calculated in the same wavelength range for an optical birefringent material ($\Delta n = 0.0015$) and a constant thickness $d = 400\mu\text{m}$ placed at 45° between ideal crossed (circles) and parallel (triangles) polarizers.

[0061] Figure 5a is a schematic representation of an optical birefringence set-up using transmitted light guided by optical fibers. Figure 5b is a schematic representation of an optical birefringence set-up using reflected light guided by optical fibers. Figure 5c is a schematic representation of an optical birefringence set-up using reflected and transmitted light guided by optical fibers.

Figure 5d is a schematic representation of an optical birefringence sensor setup using reflected light in a single optical fiber.

[0062] Figure 7 is a schematic representation of an optical birefringence sensor comprising an anisotropic material placed (at 45° between two preferably crossed polarizers) into a perforated tube which is inserted inside a filtration cartridge.

[0063] Figure 8 is a schematic cross-section of multiple optical birefringence sensors using reflected light inserted into an air purifying on a transparent wall. The multiple sensors enable the visualization of the absorbed pollutant progression into the absorbent bed.

[0064] Figure 9 is a graph showing the transmitted power (referenced to the maximum of transmission) as a function of the wavelengths for an optical birefringent porous glass flat sample placed at 45° between two crossed polarizers under dry nitrogen condition (1 L/min) for a thickness of 300 μ m and for a thickness of 600 μ m.

[0065] Figure 10 is a graph showing the transmitted power, referenced to the maximum of transmission, as a function of the wavelengths for a birefringent porous glass 600 μ m thick flat sample placed at 45° between two crossed polarizers under dry nitrogen condition (1 L/min) with no solvent or with acetonitrile (1000 ppm) or toluene (1000 ppm).

[0066] Figure 11 shows the transmitted power, referenced to the maximum of transmission, at 450 nm and 600 nm, as a function of time, for a birefringent porous glass 600 μ m thick flat sample placed at 45° between two crossed polarizers, under dry nitrogen condition (1 L/min), with no solvent or with toluene (1000 ppm). The solvent is removed from the fiber using a moderate

vacuum (30 mmHg). Addition and removal of solvent are indicated into the graph.

[0067] Figure 12 shows the transmitted power, referenced to the maximum of transmission, at 450 nm and 600 nm, as a function of time, for a birefringent porous glass 600 μ m thick flat sample placed at 45° between two crossed polarizers, under dry nitrogen condition (1 L/min), with no solvent or with acetonitrile (1000 ppm). The solvent is removed from the fiber using a moderate vacuum (30 mmHg). Addition and removal of solvent are indicated into the graph. The experiment is repeated twice to show the reproducibility.

[0068] Figure 13a illustrates the variation intensity, measured at 550 nm and 800 nm with a spectrometer, of an optical birefringent porous glass sensor in transmission mode (similar to Figure 5a) inserted in the middle of an activated carbon bed of an organic vapor cartridge challenged at 32 L/min with 1000 ppm of toluene. The intensity at 550 nm corresponds approximately to a maximum transmission of the birefringent porous glass, whereas the intensity at 800 nm corresponds to a minimum transmission. The vertical dash line shows the breakthrough time representing 5 ppm of toluene measured by a gas chromatography spectrometer. The sensor shows a signal variation at approximately half of the breakthrough time. At 550 nm, the intensity is decreased by a factor of about 7.8, while at 800 nm the intensity is increased by a factor of about 58.

[0069] Figure 13b illustrates the intensity ratios of the signals measured at 550 nm and at 800 nm in the experiment described in the Figure 12a. The ratio variation is about a factor of 450 between beginning and end of cartridge challenge experiment; and

[0070] Figure 13c illustrates spectra measured with a spectrometer during the experiment described in Figure 13a for various times (0 min start, 60

and 70 min sensor signal variation and 120 min 5 ppm breakthrough of cartridge).

[0071] In summary, according to the first aspect of the present invention, a porous glass exhibiting optical birefringence may be used to detect liquid, gas or vapors of chemical substances. The porous glass is made from a phase separation process followed by chemical etching from which the optical birefringence can be controlled. Absorption of the liquid into the pores or gas or vapor pollutants through capillary condensation into the pores modifies the optical birefringence of the porous glass. Such changes can be detected by observing a color shift of the light transmitted through the porous glass placed between two crossed polarizers, or by comparing the transmitted light intensity at different wavelengths.

[0072] Alternatively, according to the first aspect of the present invention, an optically birefringent multilayer porous thin film may be used to detect liquid, gas or vapors of chemical substances. The optical birefringence of a multilayer thin film changes in the same manner than that of a porous glass and can be detected in the same manner as explained above.

[0073] Moreover, still according to the first aspect of the present invention, an optically birefringent polymer, an optically birefringent polymer composite, or an optically birefringent multilayer polymer film may be used to detect liquid, gas or vapors of chemical substances. The optical birefringence of the polymer changes in presence of the chemical substances due to the swelling of the polymer. These changes can be measured in the same manner than with porous glass as explained hereinabove.

[0074] Turning now to the second aspect of the present invention, the use of dichroism or selective absorption to observe a change in optical anisotropy may be performed with a set-up as illustrated in Figure 1c for example.

[0075] Figure 1c is a schematic representation of a dichroism or an anisotropic diffusion configuration set-up according to the present invention. The polarizer and analyzer are optional depending on the nature of the anisotropy. Obviously, other configurations are possible.

[0076] According to this aspect of the invention, an optically dichroic polymer, an optically dichroic polymer composite, or an optically dichroic multilayer polymer film may be used to detect liquid, gas or vapor of chemical substances. The dichroism (i.e. selective absorption of a polarization state of light) of the polymer changes in presence of the chemical substances due to the swelling of the polymer. This change can be observed by measuring the intensity changes of a given polarization state of light or by measuring the intensity changes of the ratio of two mutually orthogonal states of polarization.

[0077] In the third aspect of the present invention, the change in optical anisotropy is observed as an anisotropic diffusion of light or as an anisotropic scattering of light, and a set-up such as the one illustrated in Figure 1c for example may be used therefor.

[0078] According to this aspect of the present invention, an optically anisotropic scattering or an anisotropic diffusing optical material, such as, but not limited to, a porous glass or a composite polymer, is used to detect liquid, gas or vapors of chemical substances. The optical anisotropy of the scattering of light or of the diffusion of light is affected in the same manner than explained above in case of porous material (glass, thin film, etc.) or in case of polymer. In case of polarization-dependent scattering or diffusion, this change can be observed by measuring the intensity changes of a given polarization state of light or by measuring the intensity changes of the ratio of two orthogonal states of polarization. Otherwise these changes can be observed by measuring the geometric distribution of the diffused or scattered light in two mutually orthogonal

directions.

[0079] People in the art will appreciate that the present invention provides chemical sensors, which are highly sensitive, simple and inexpensive to produce, as well as robust, and which can be used to detect a range of chemical species. A hydrophobic agent or treatment may be applied on the anisotropic material (porous glass, polymer, etc) forming the sensor so to reduce the sensitivity thereof to water vapors while maintaining its sensitivity to other chemicals.

[0080] Interestingly, the present invention is suited for making an end of service life indicator for example, which can be incorporated in air purifying device so as to provide a warning when the life of a filter is near to exhaustion. For example, Figure 6 illustrates an air purifying cartridge with an optical birefringence sensor using transmitted light guided by optical fibers showing the positioning of the sensor inside the cartridge.

[0081] Although the present invention has been described hereinabove by way of embodiments thereof, it can be modified, without departing from the spirit and nature of the subject invention as defined herein.

ABSTRACT OF THE DISCLOSURE

The present invention provides a chemical sensor and a method for detecting the presence of liquid, gas or vapor of chemical substances through changes in the optical anisotropy of the sensor upon exposure to these liquid, gas or vapor substances. In a first aspect of the present invention, the change in optical anisotropy is observed as optical birefringence. In a second aspect of the present invention, the change in optical anisotropy is observed as dichroism or selective absorption. In a third aspect of the present invention, the change in optical anisotropy is observed as an anisotropic diffusion of light or an anisotropic scattering of light.

Fig. # 1a Transmission

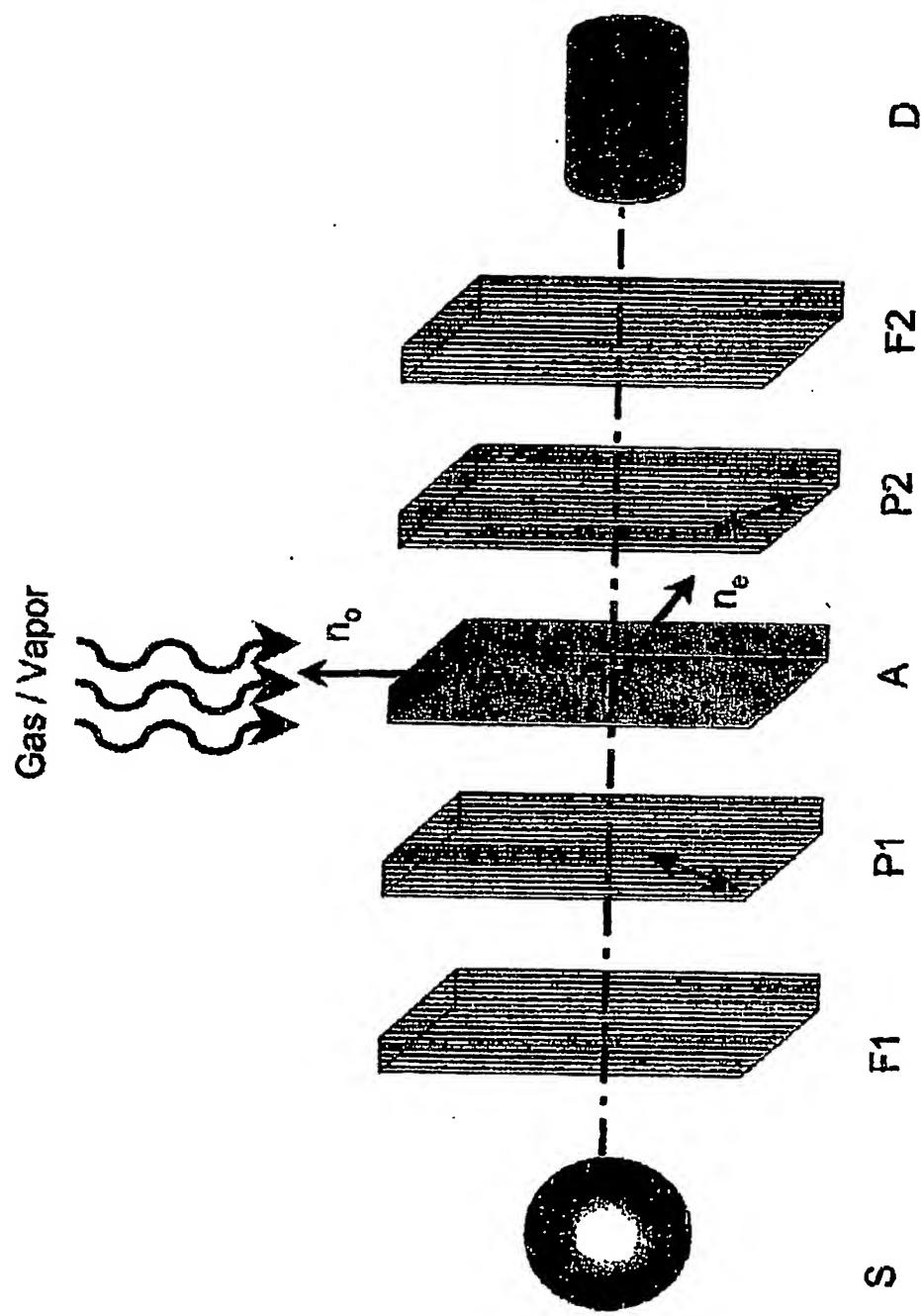
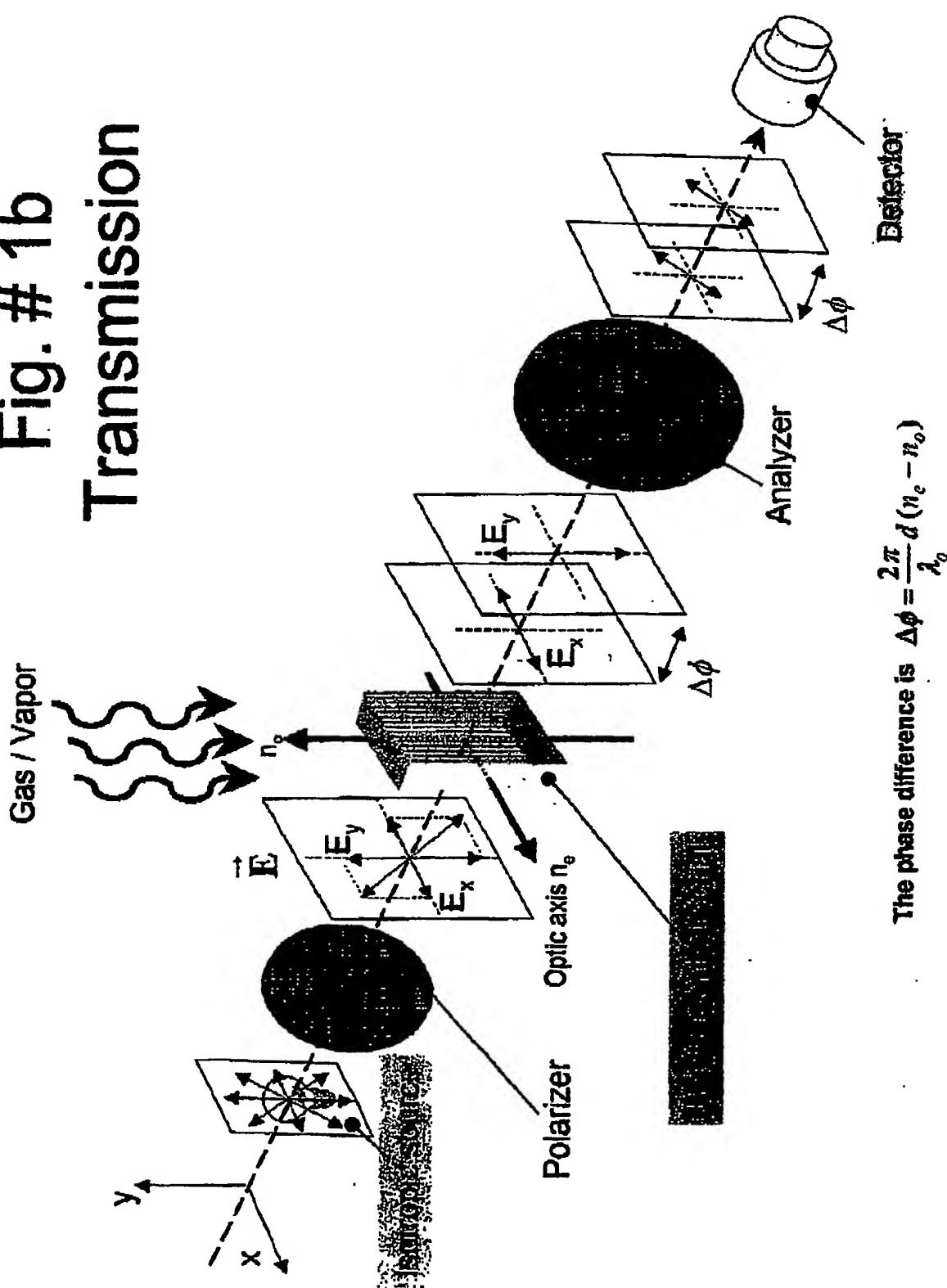


Fig. # 1b
Transmission



The phase difference is $\Delta\phi = \frac{2\pi}{\lambda_0} d (n_e - n_o)$

Fig #1C Dichroic material

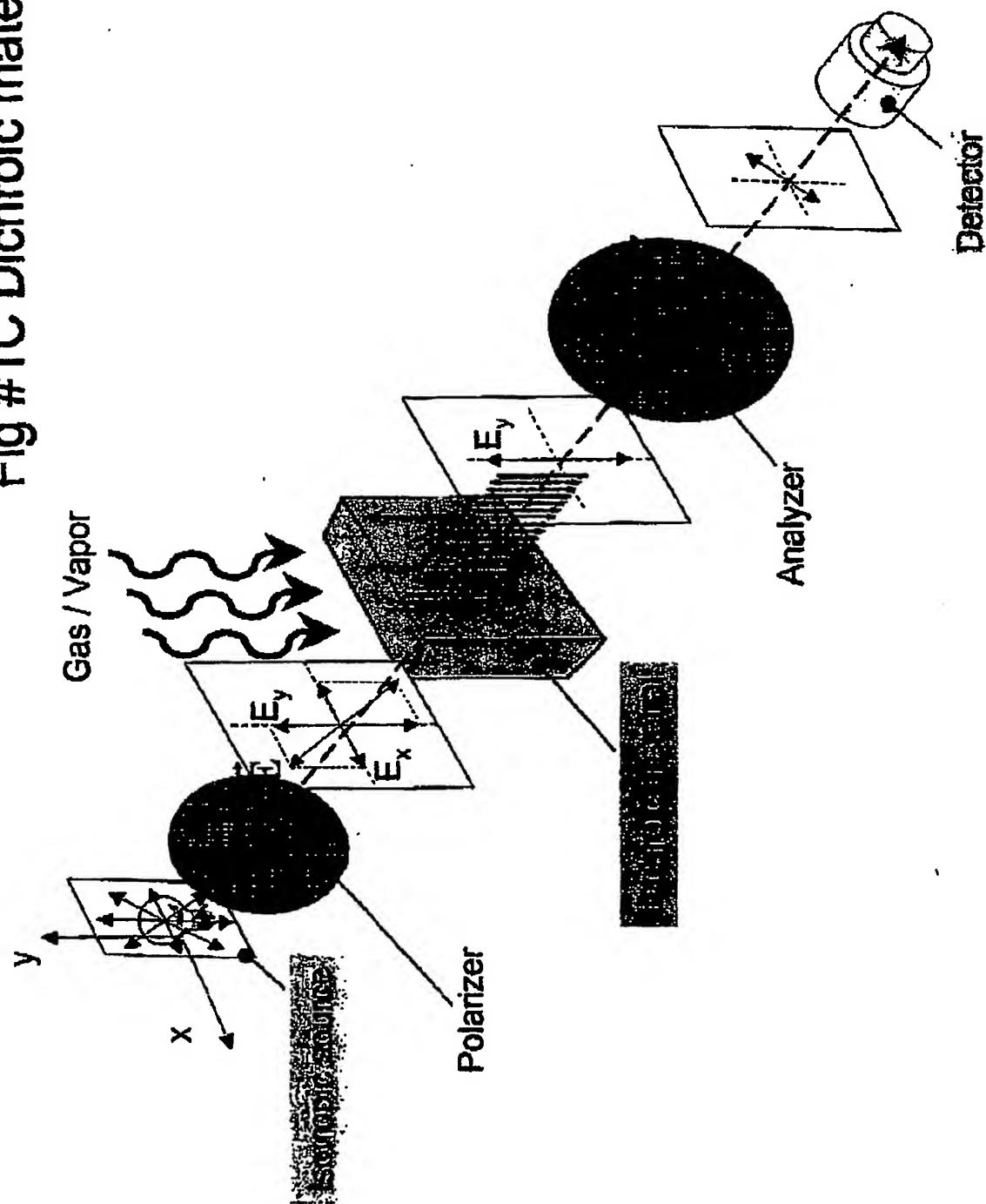
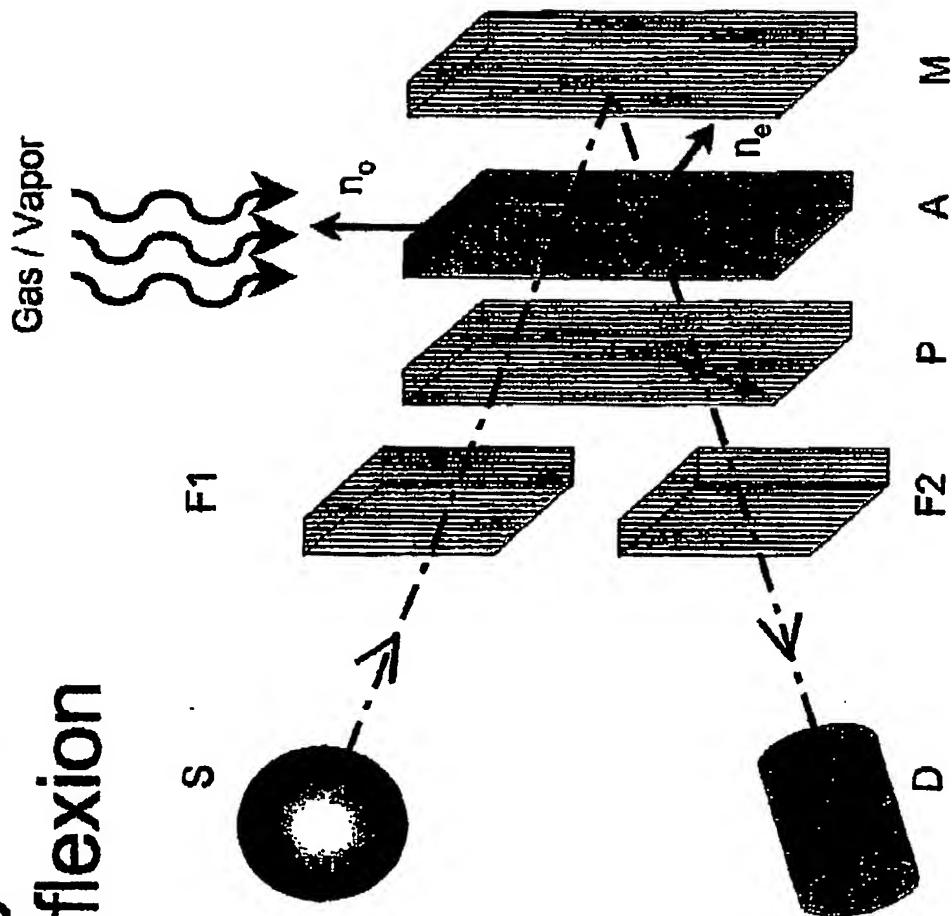


Fig. # 2a
Reflexion



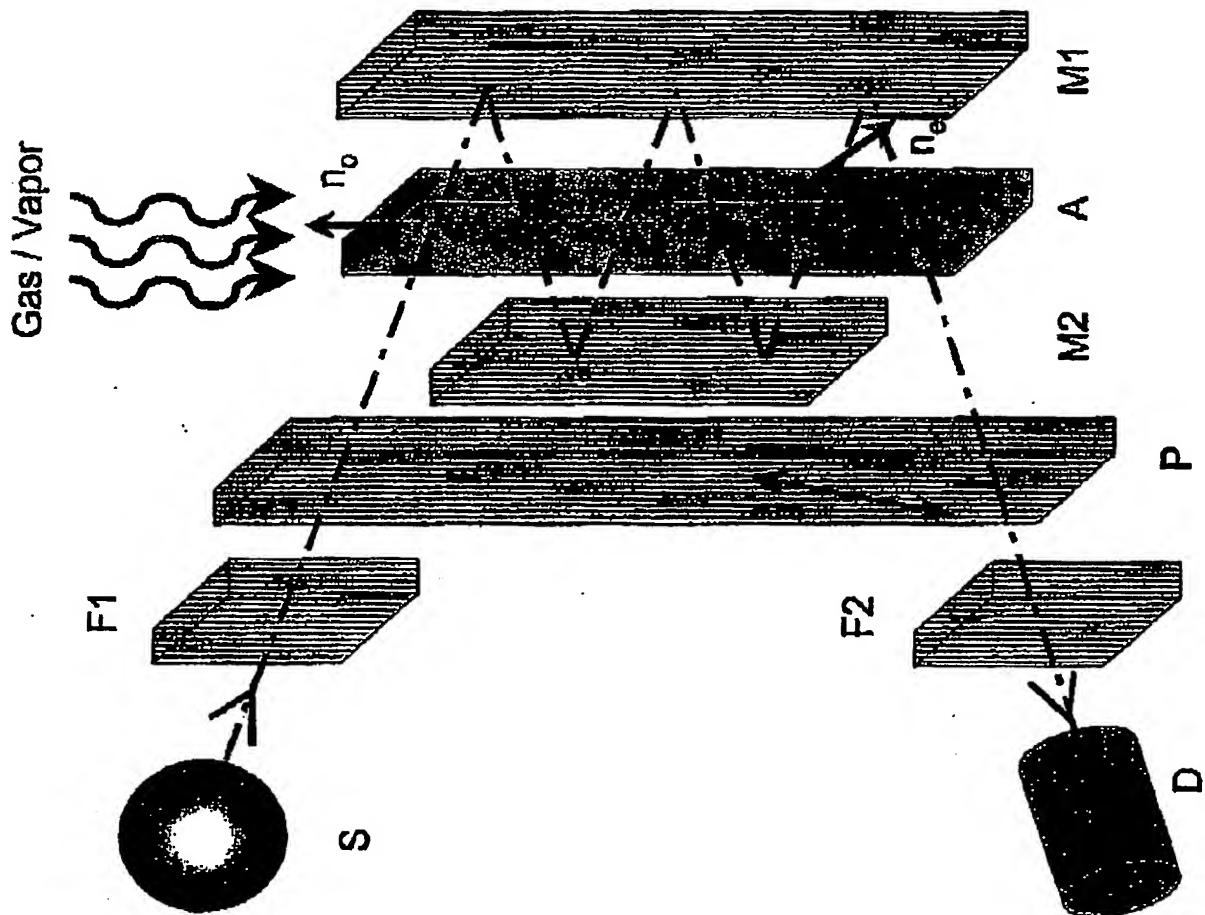


Fig. # 2b
Multiple
Reflexions
Parallel
Polarizers

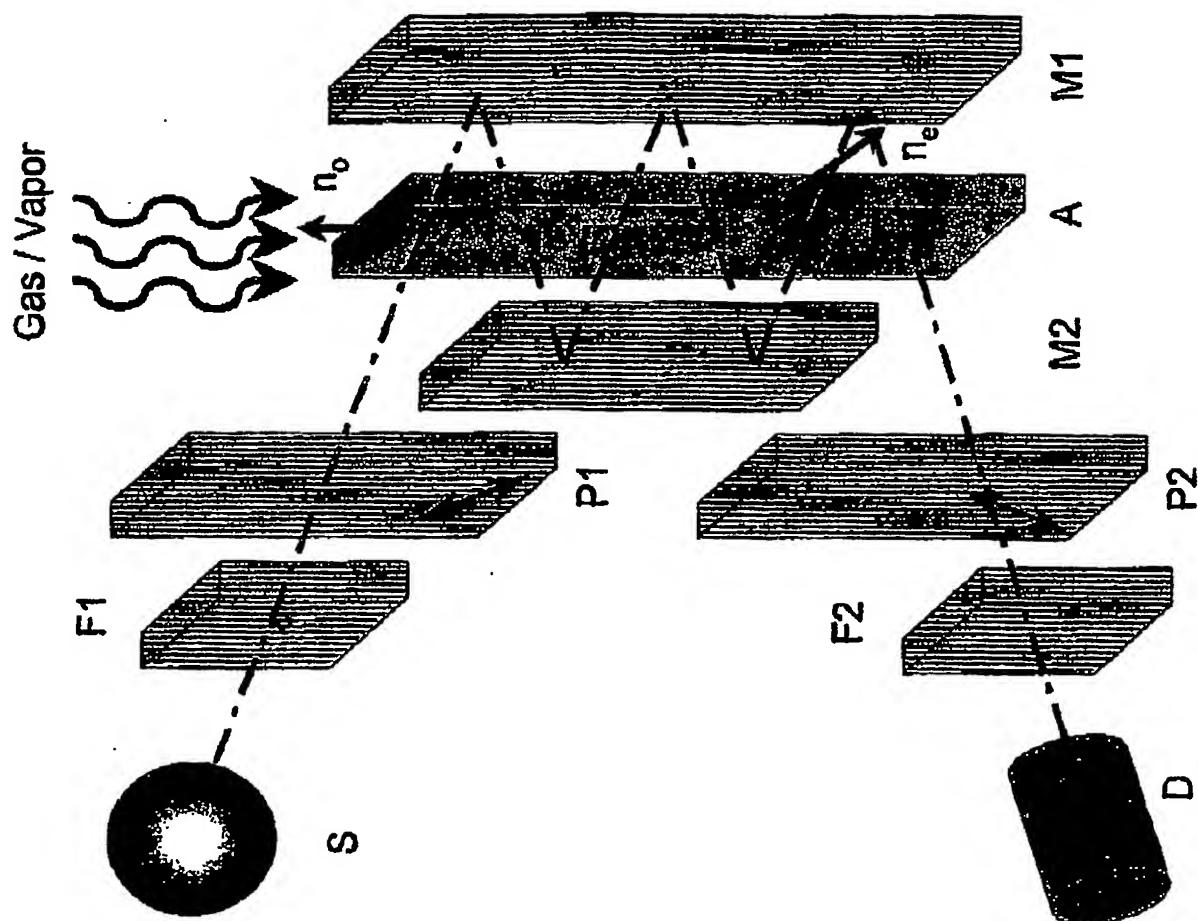


Fig. # 2C
Multiple
Reflexions
Crossed
Polarizers

Fig. # 3a
Transmission
Reflexion

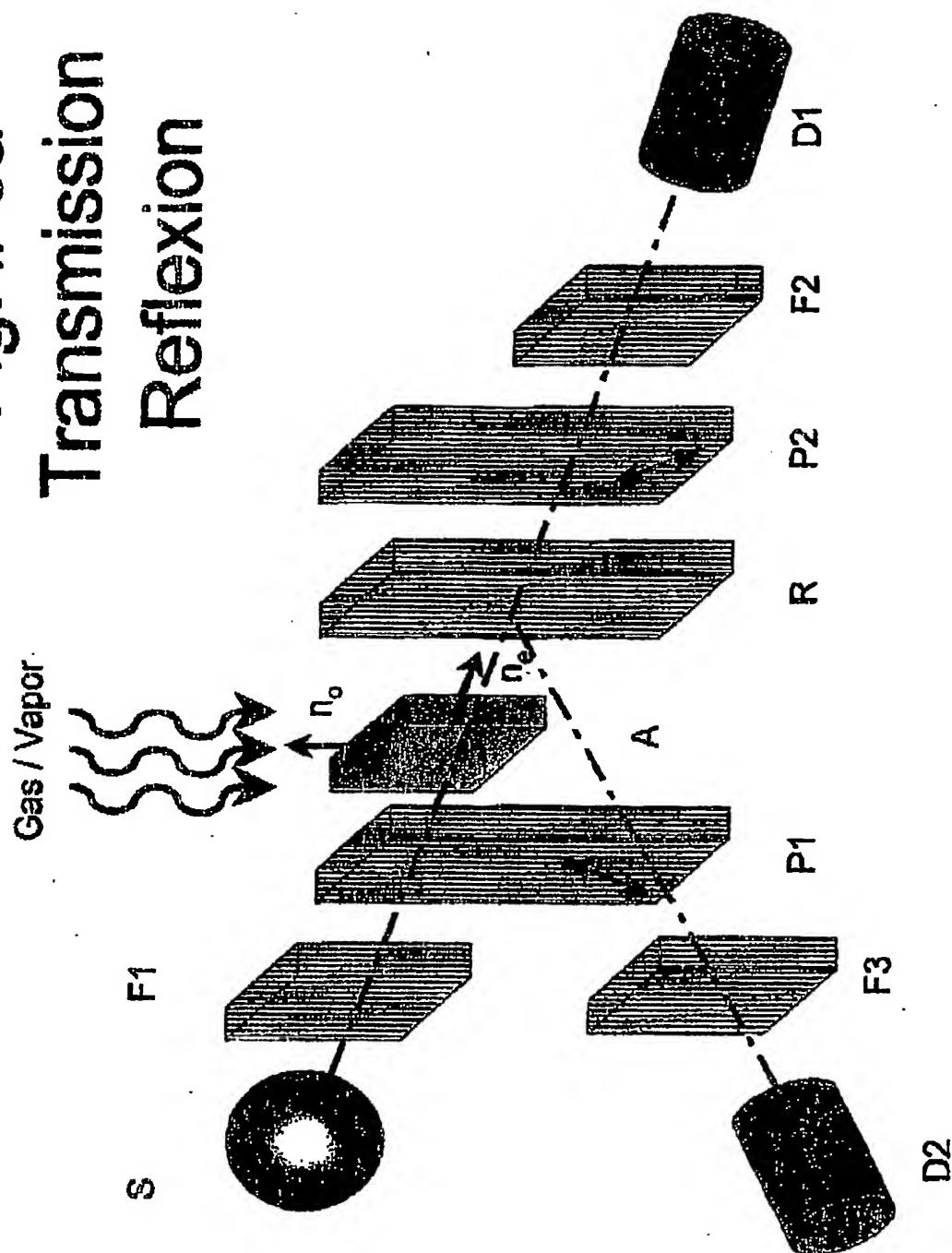


Fig. # 3b

Transmission Reflexion x2

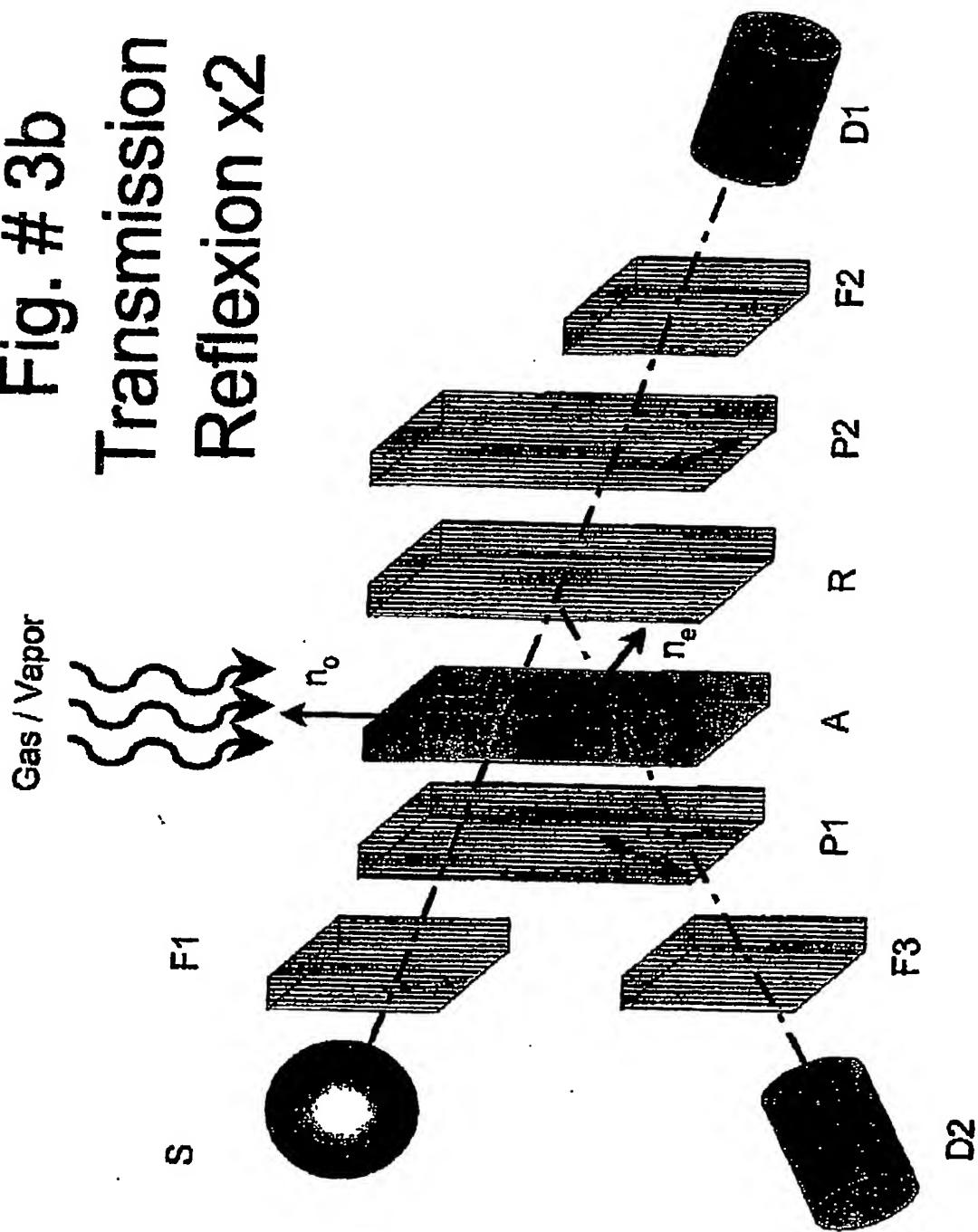


Fig #4a Effect of birefringent material thickness (crossed polarizers)

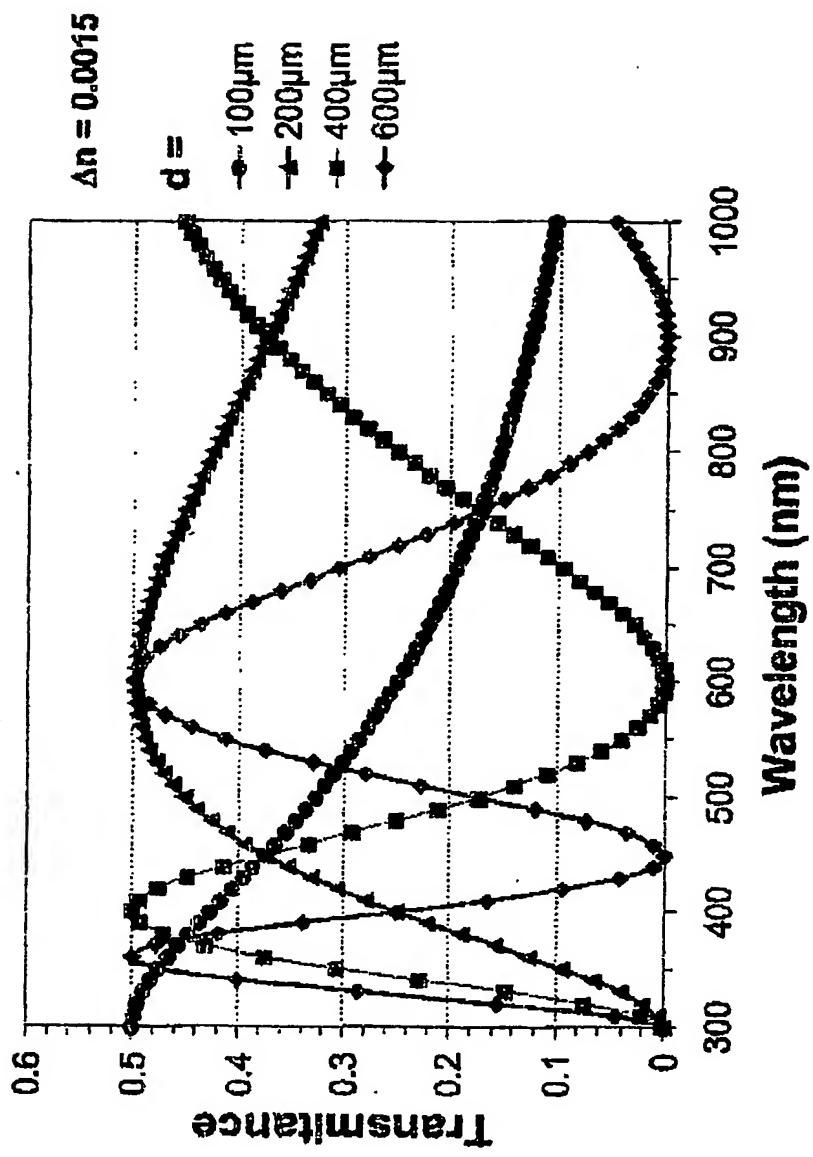


Fig #4b Effect of birefringence (crossed polarizers)

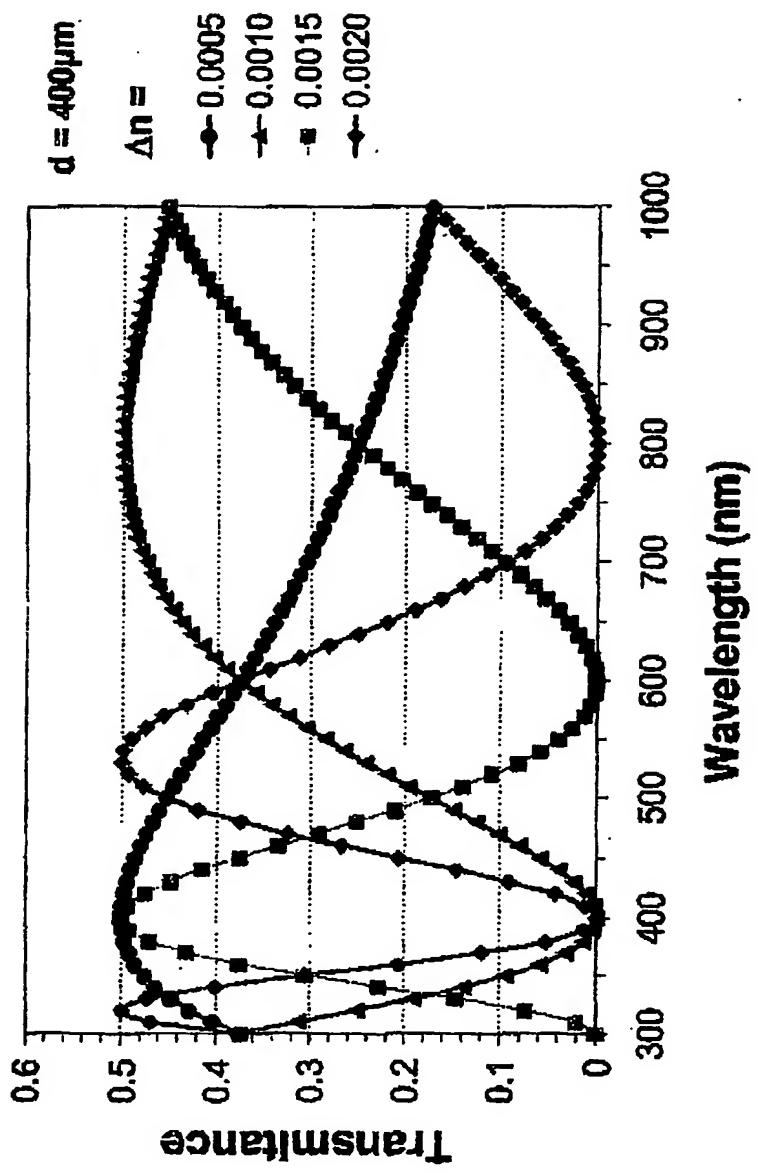
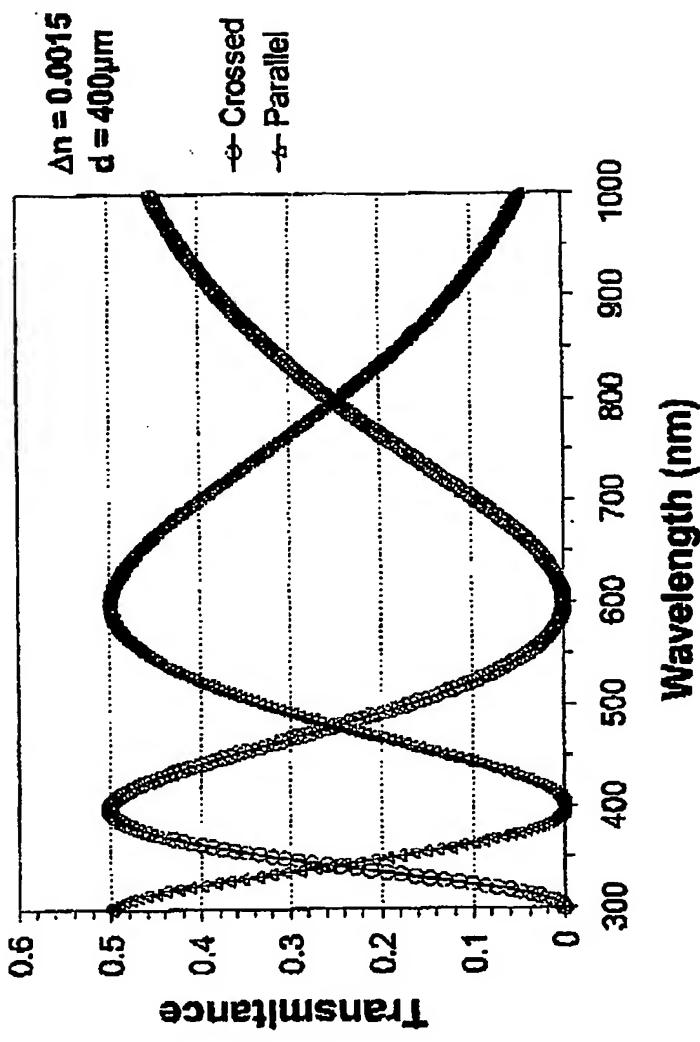
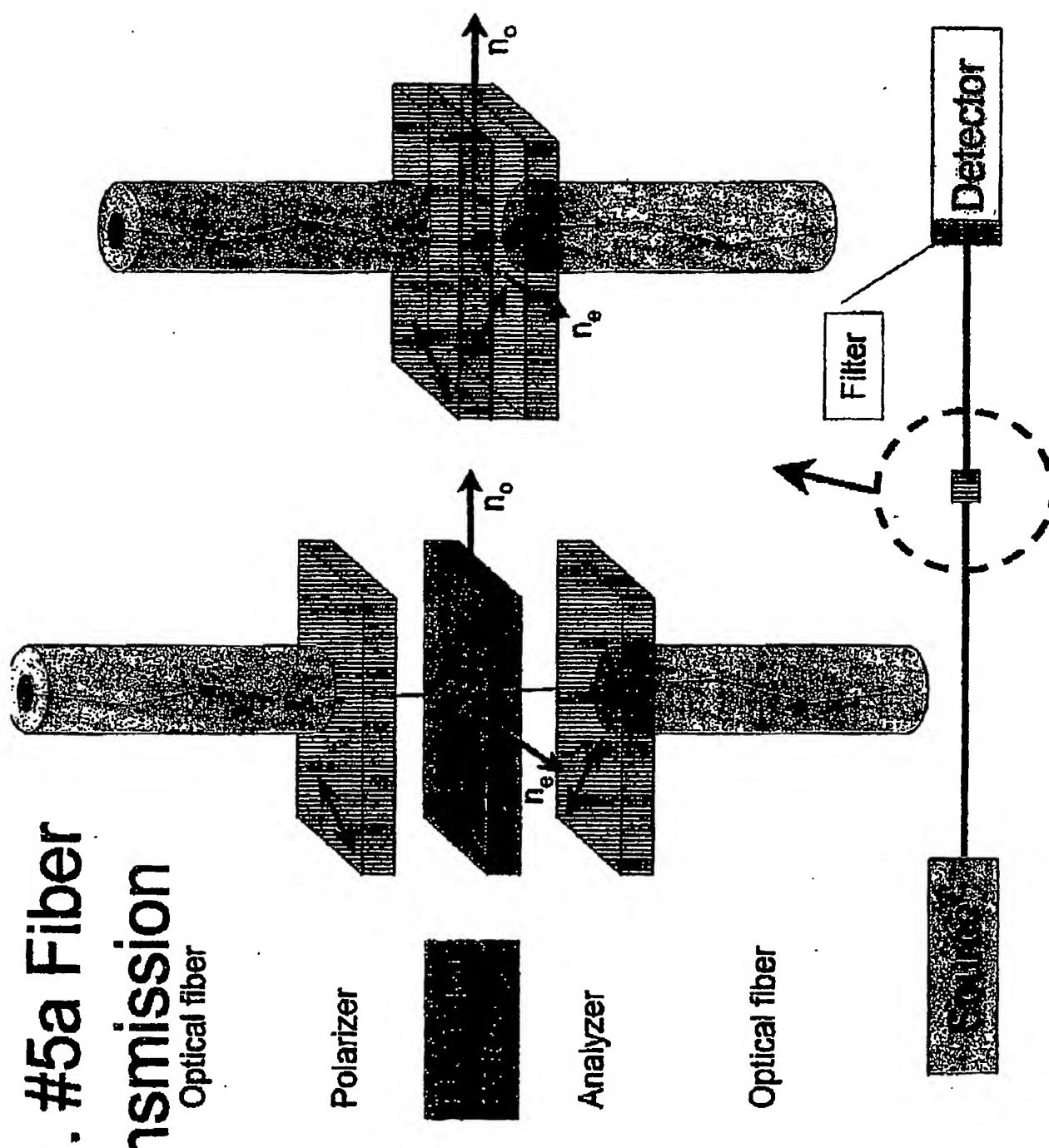
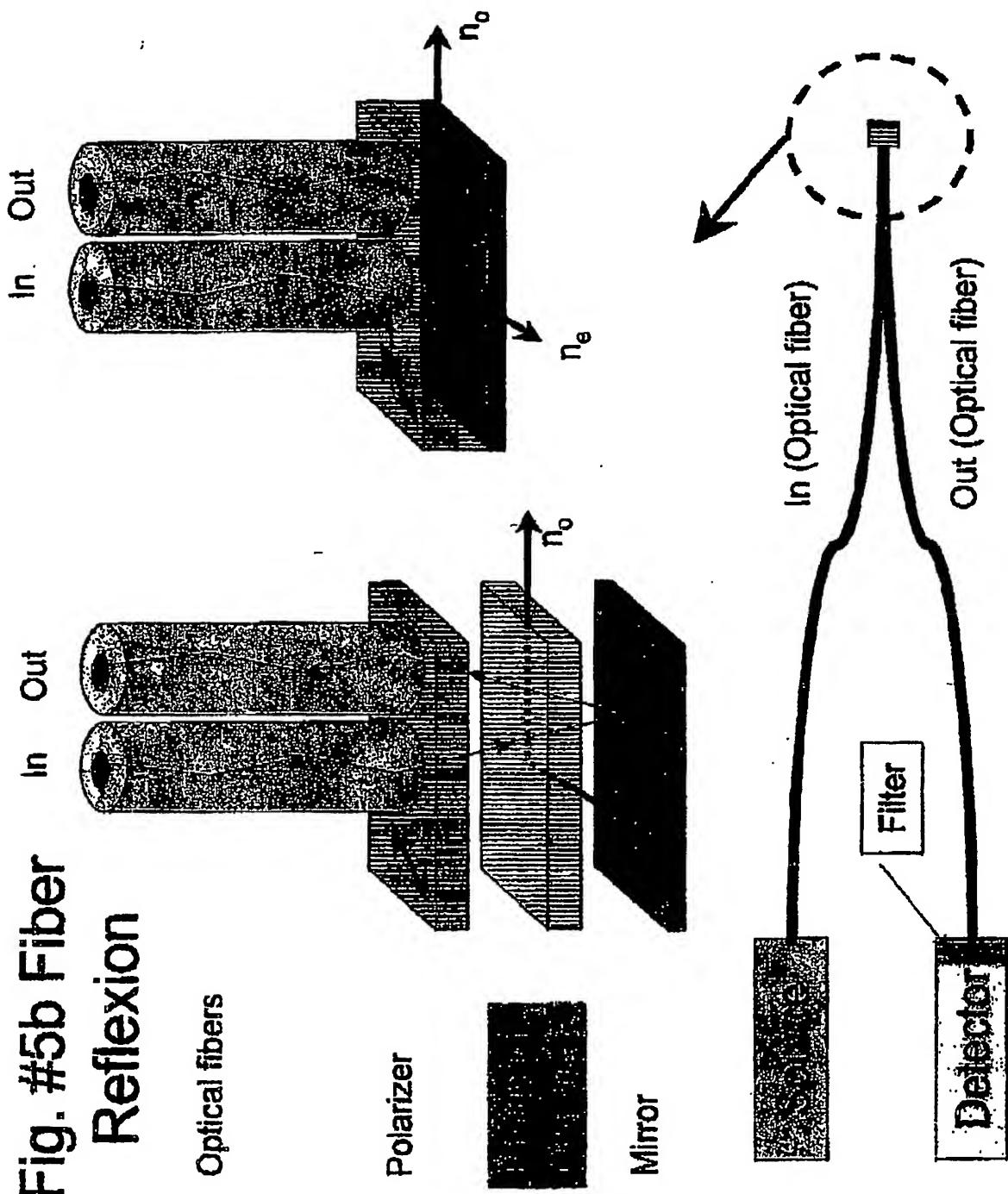


Fig #4c Effect of polarizers orientation





**Fig. #5b Fiber
Reflexion**



**Fig. #5c Fiber
Reflexion /
Transmission**

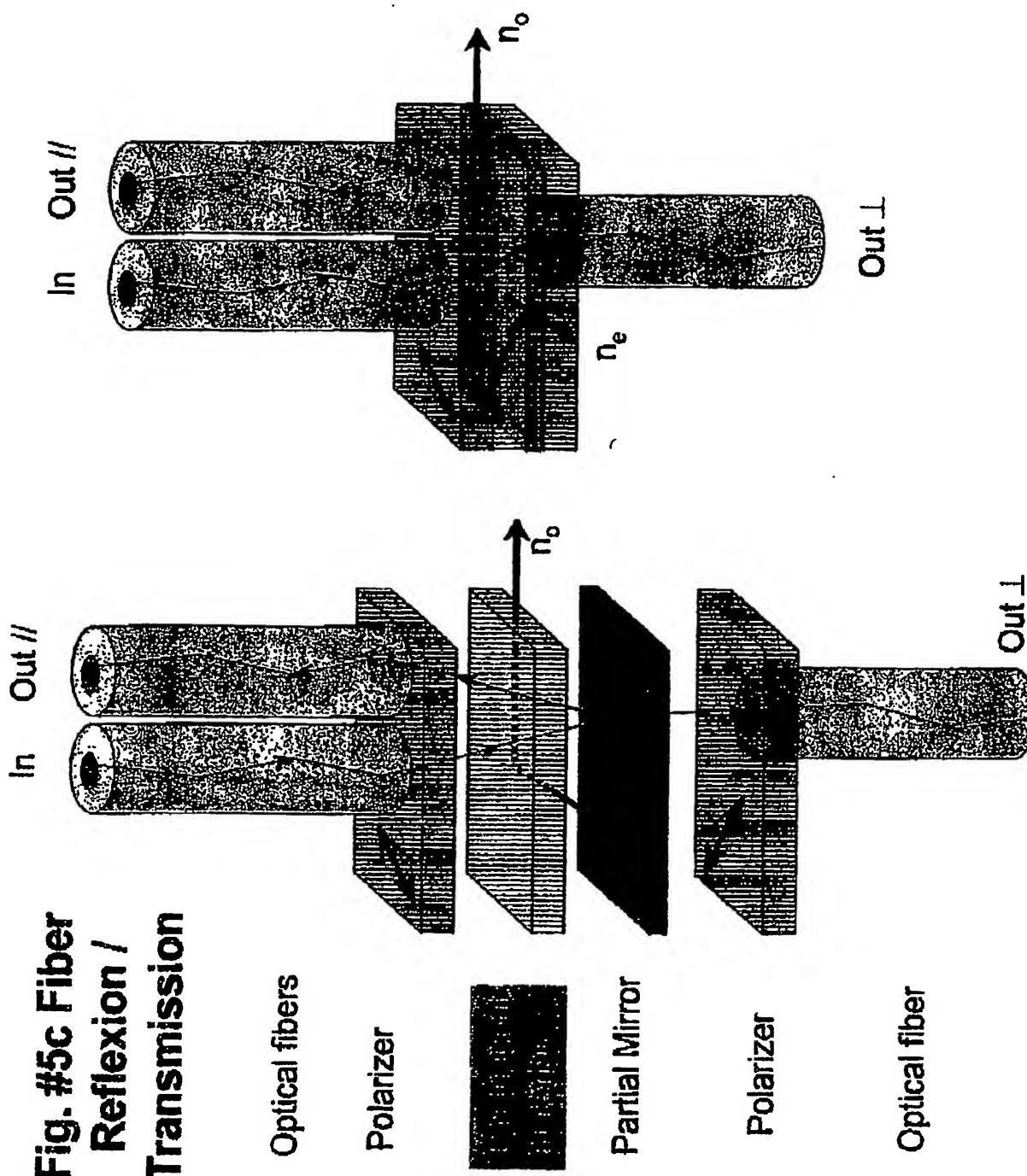
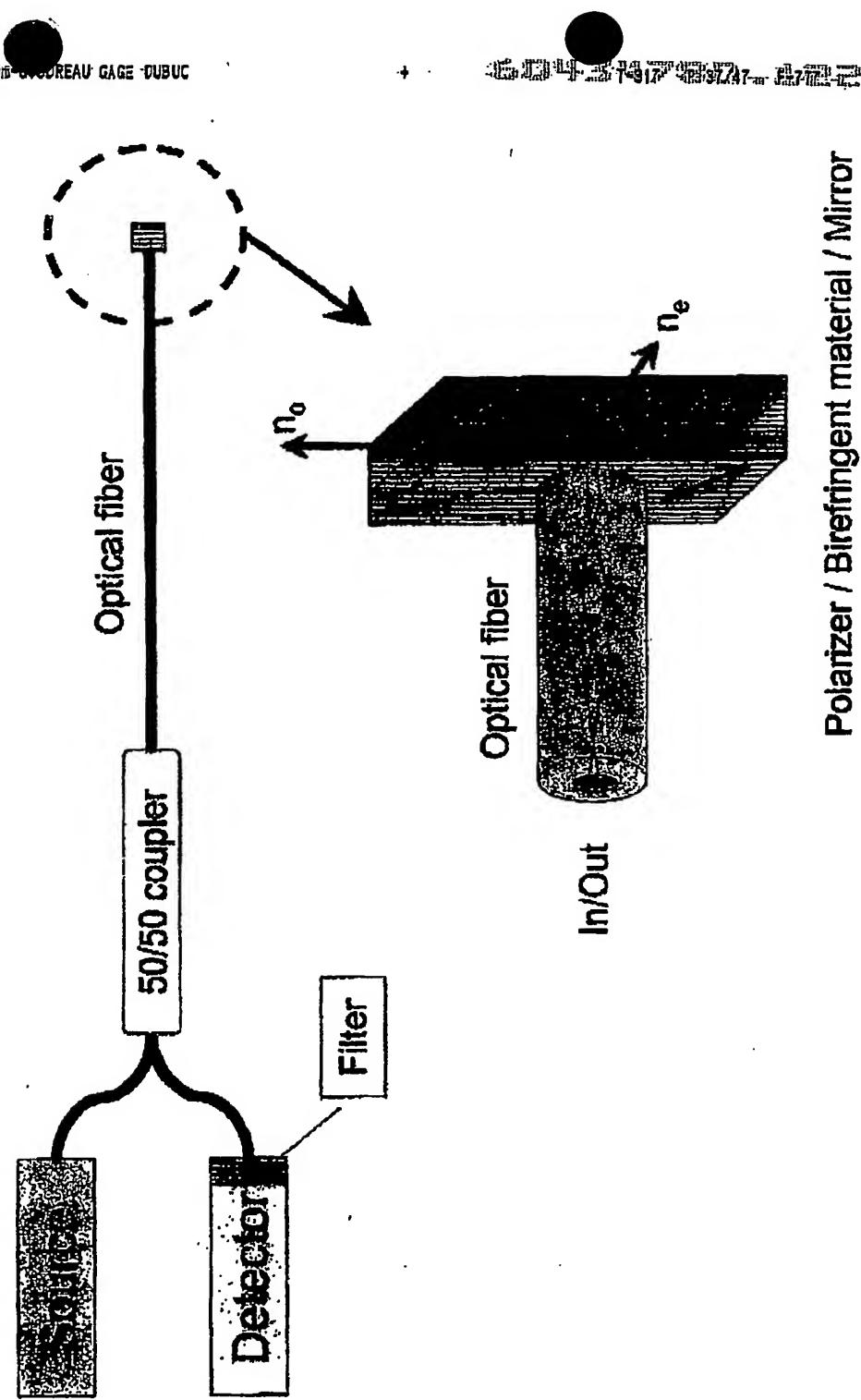
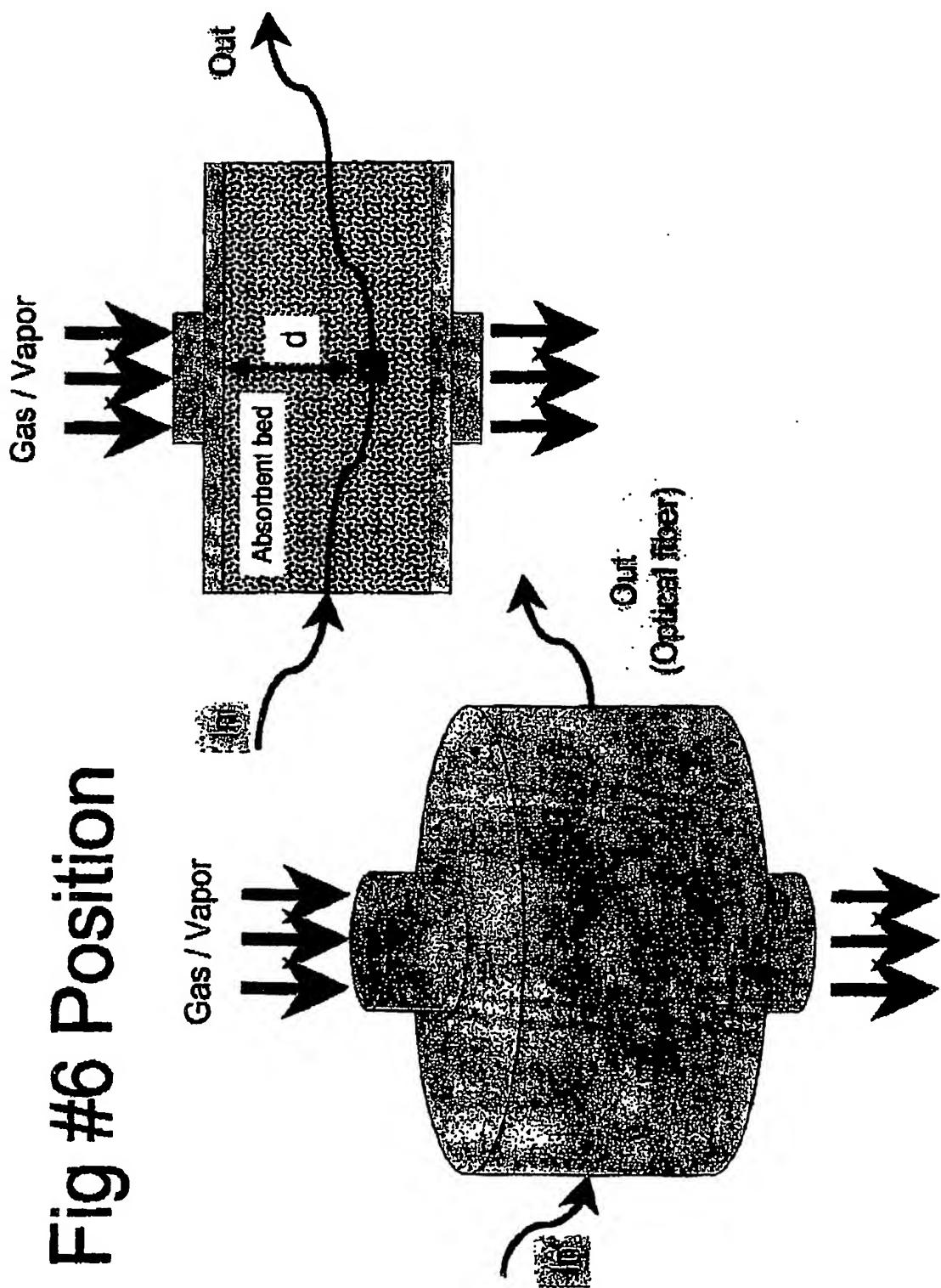


Fig #5d Single fiber sensor



Polarizer / Birefringent material / Mirror

Fig #6 Position



**Fig #7 Tube
sensor**

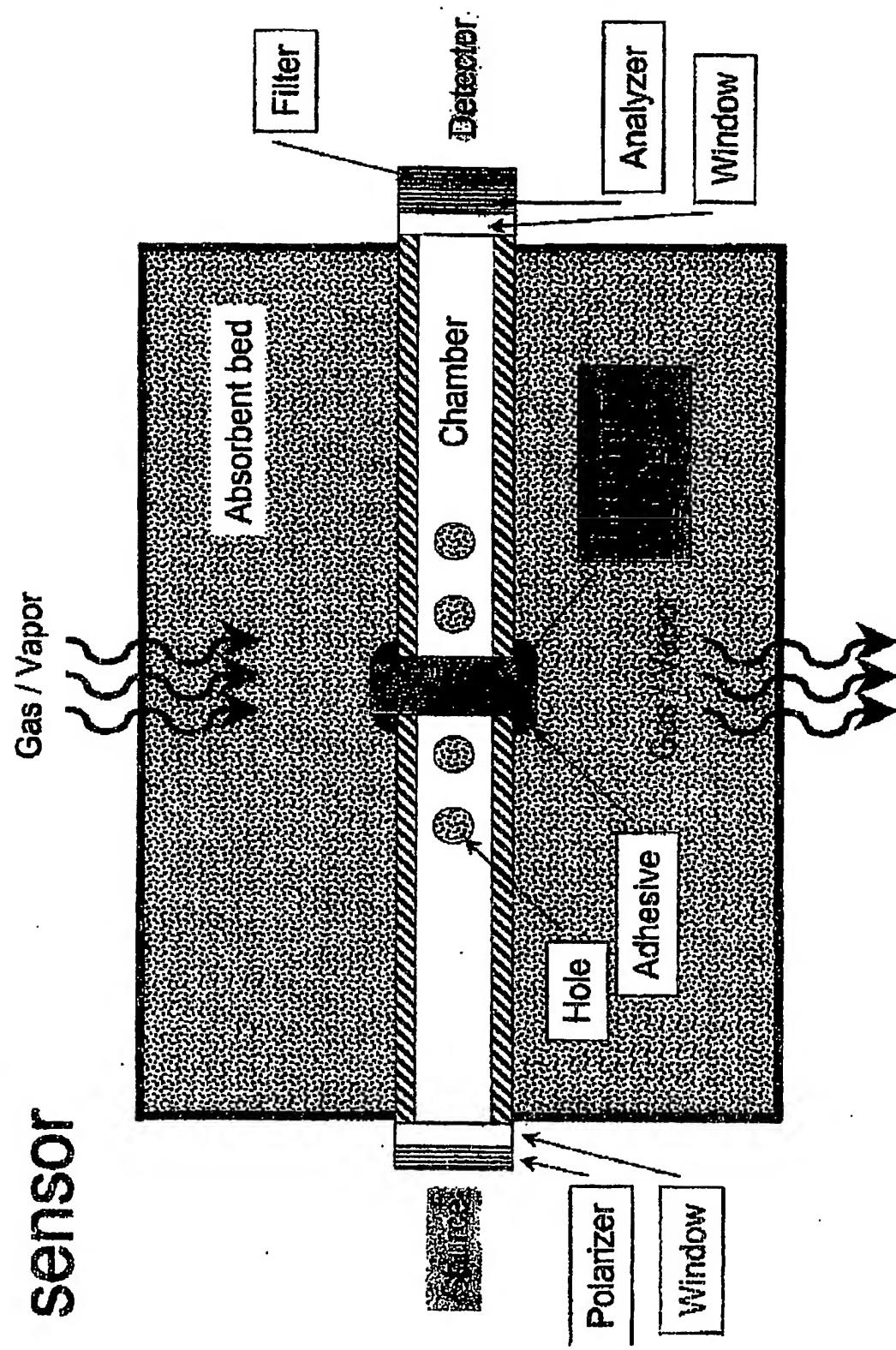


Fig #8 Multi
sensor

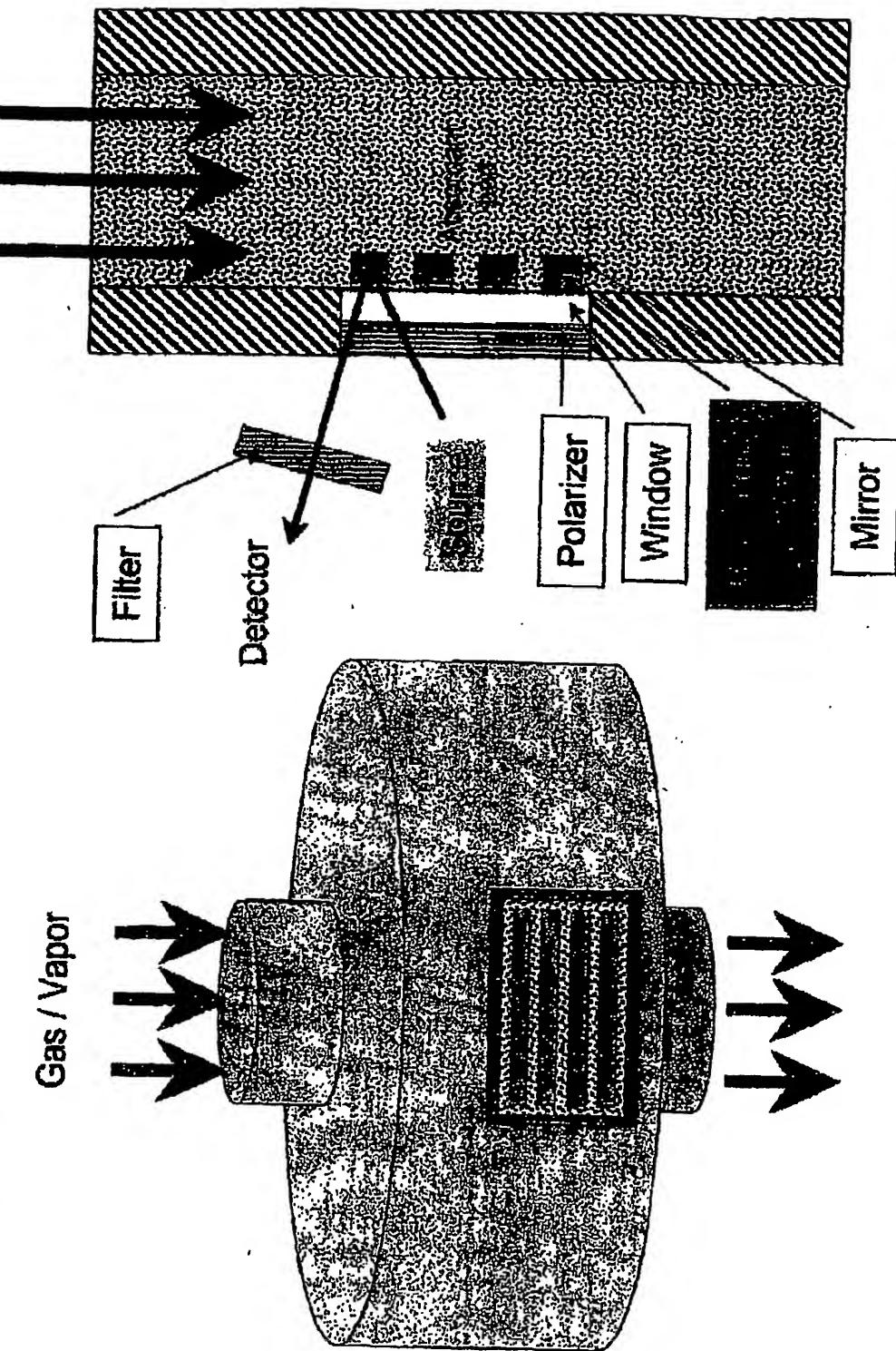


Figure #9 : Dry N₂ 1Lpm

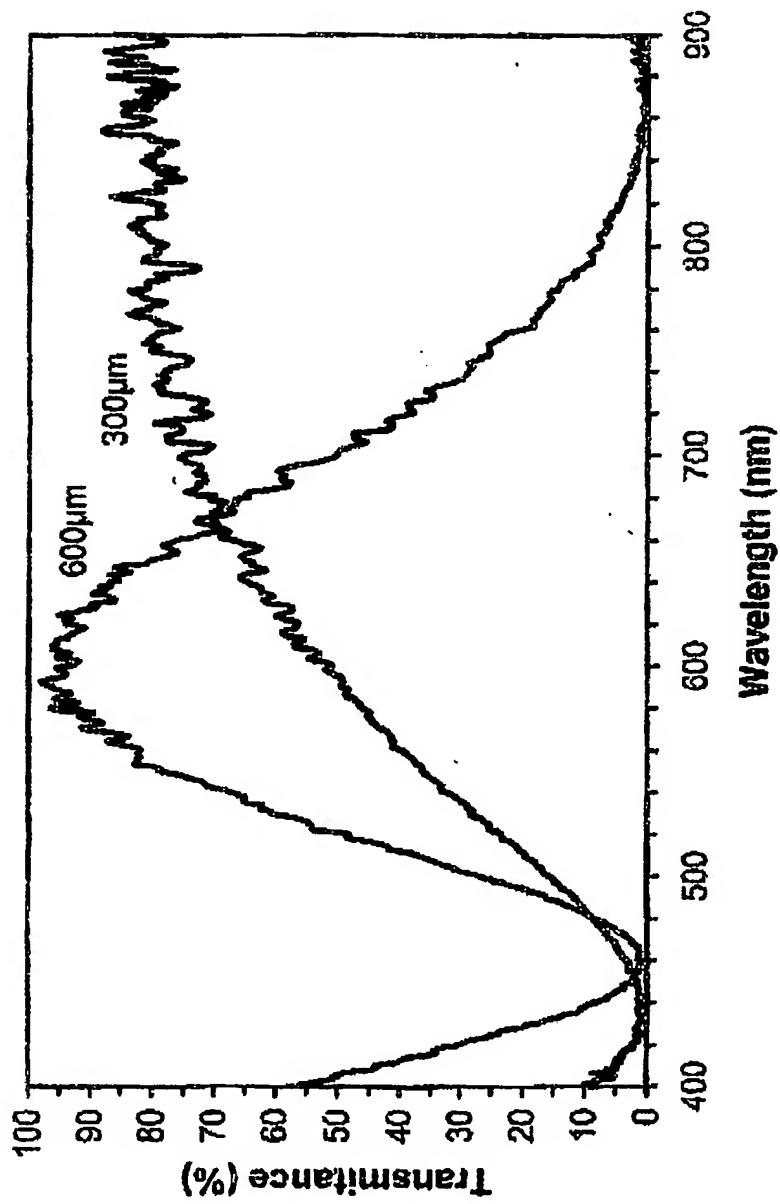


Figure # 10 : 1000ppm 1Lpm

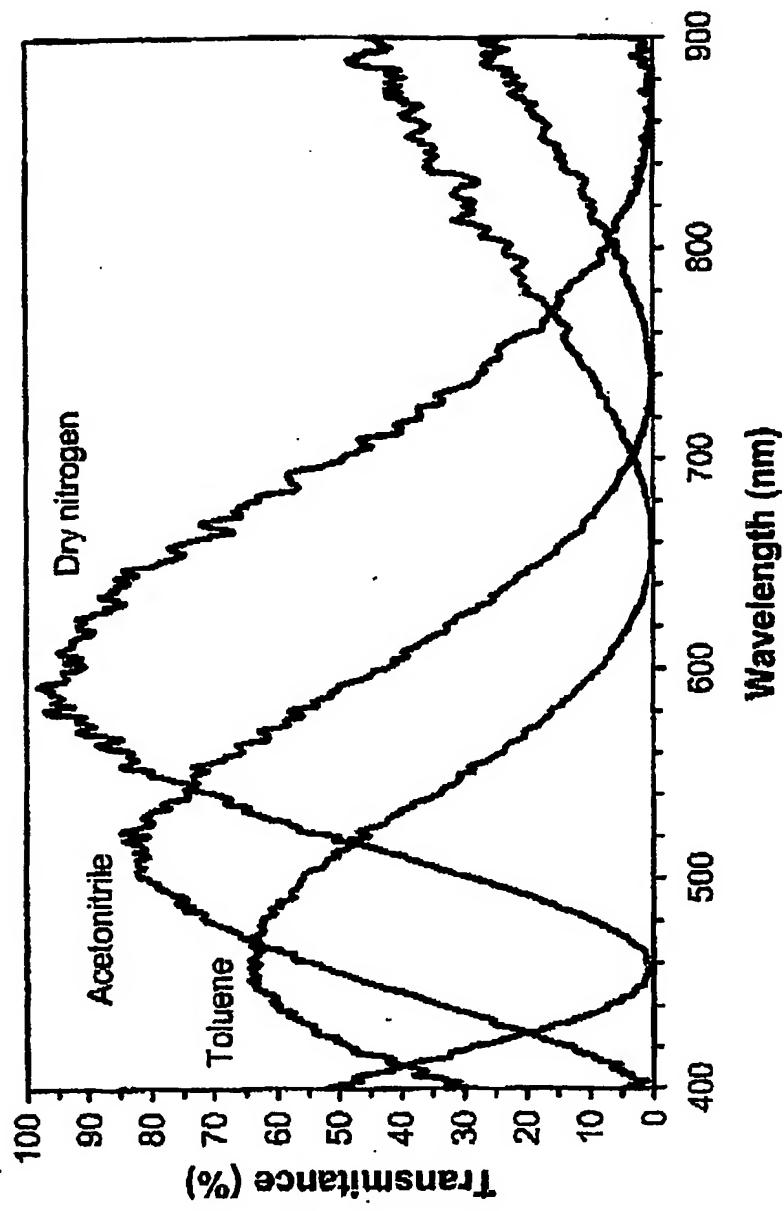


Figure # 11 : Toluene 1000ppm 1Lpm

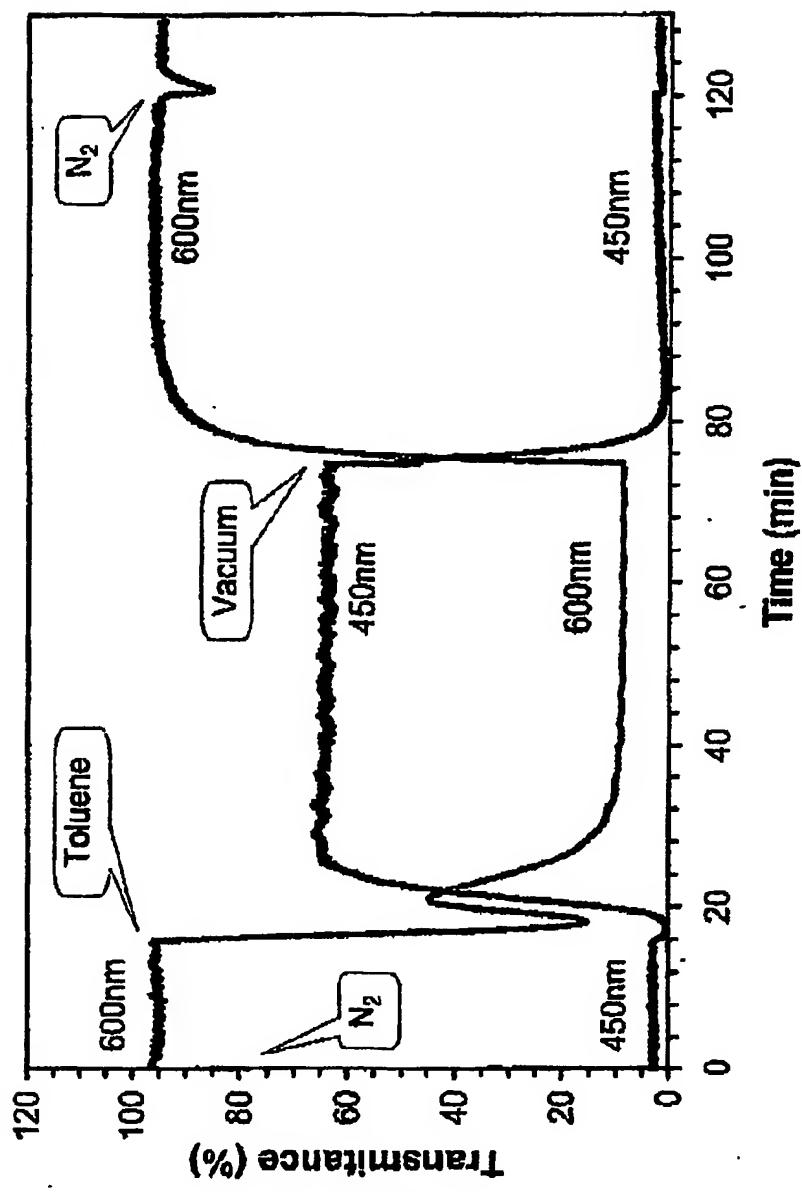


Figure # 12 : Acetonitrile 1000ppm
1Lpm

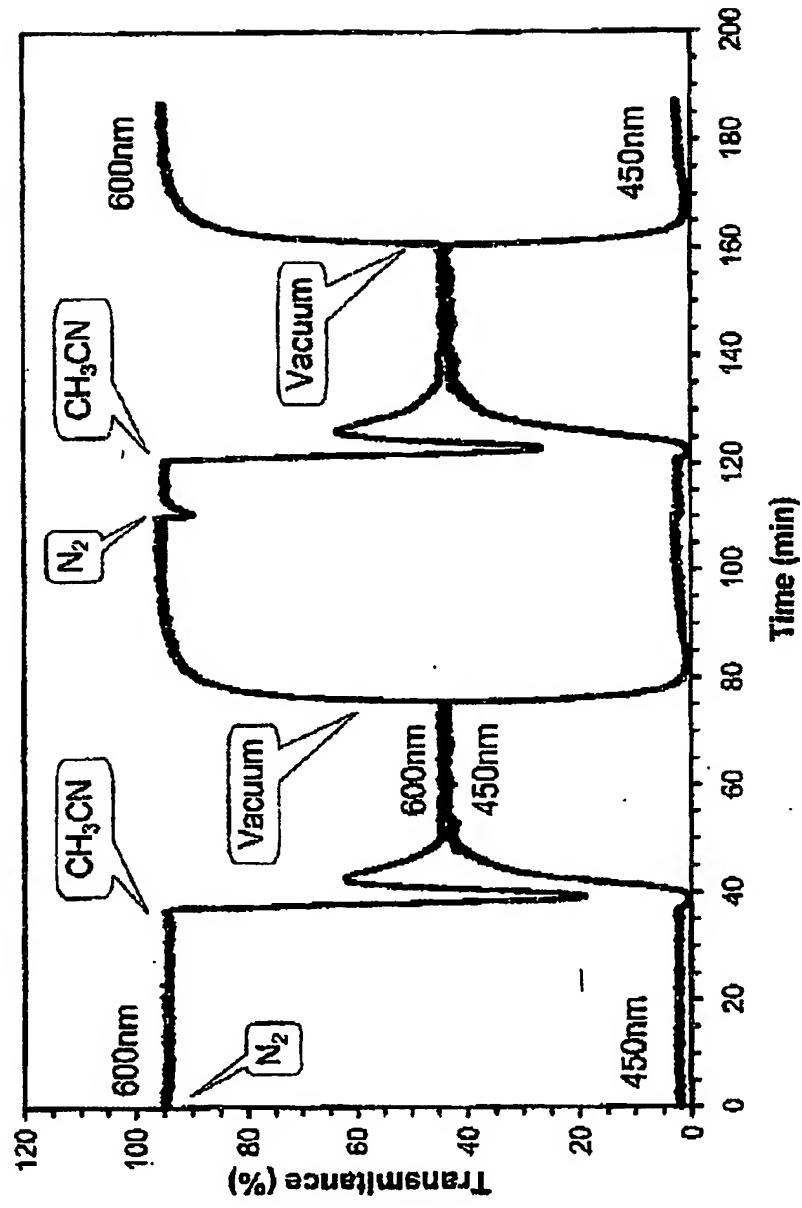


Fig #13a transmission sensor in
cartridge. Toluene 1000ppm 32L/min
Intensity variation with time

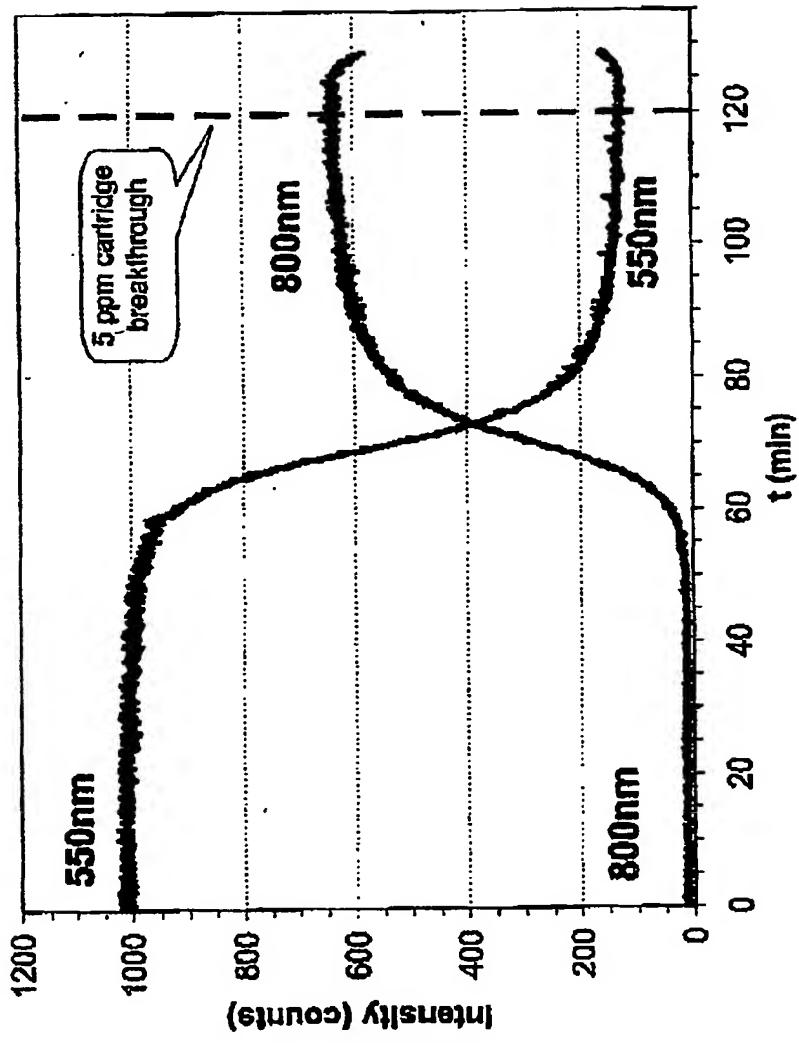
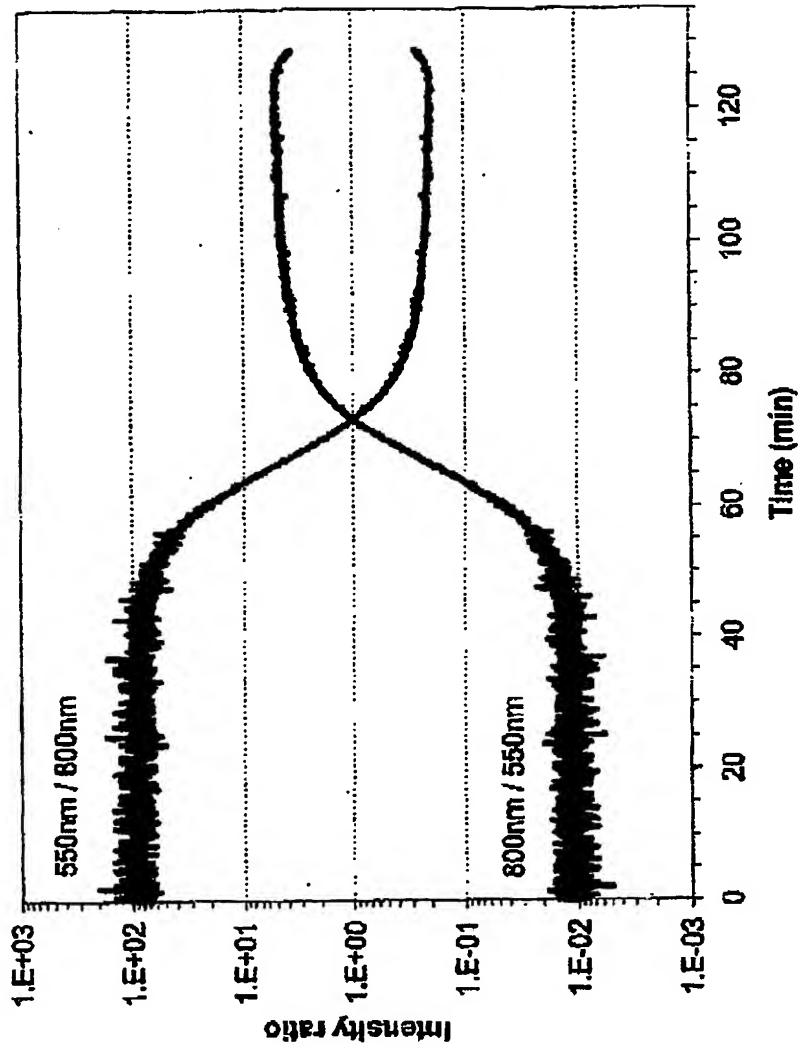
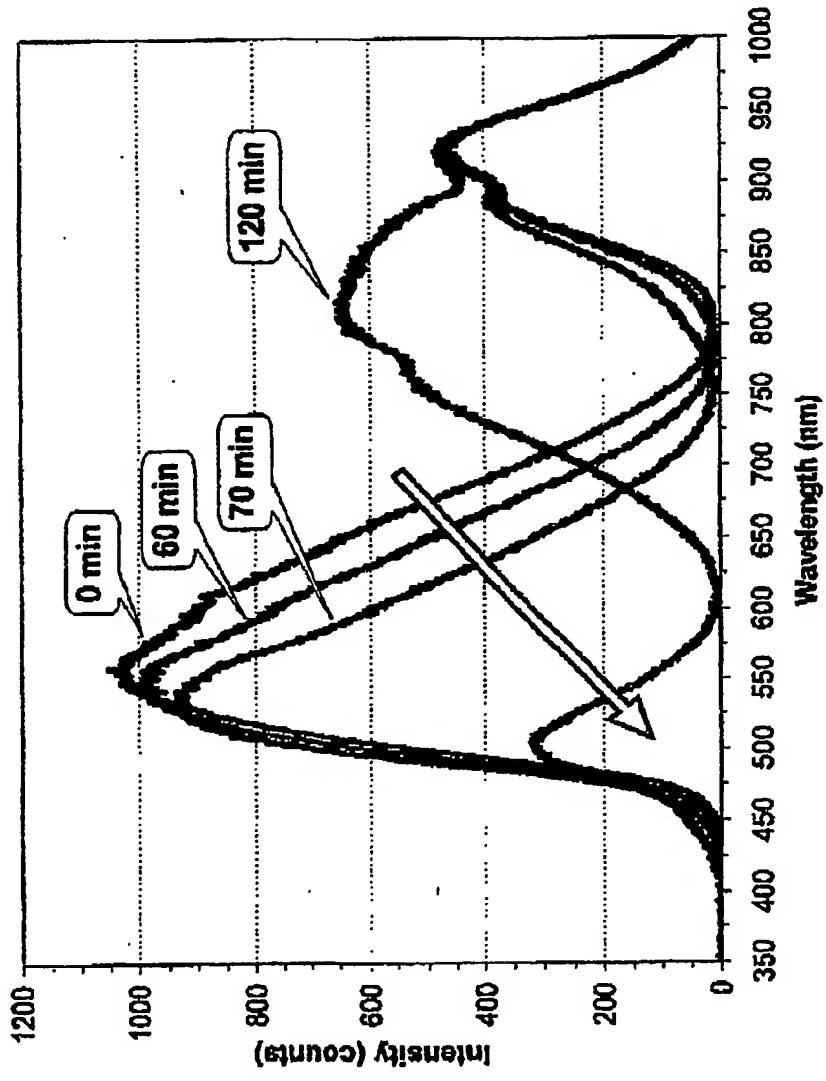


Fig #1 3D transmission sensor in
cartridge. Toluene 1000ppm 32L/min
Signal ratios



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Fig #1 ^{13}C transmission sensor in cartridge. Toluene 1000 ppm 32L/min Transmission spectra



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